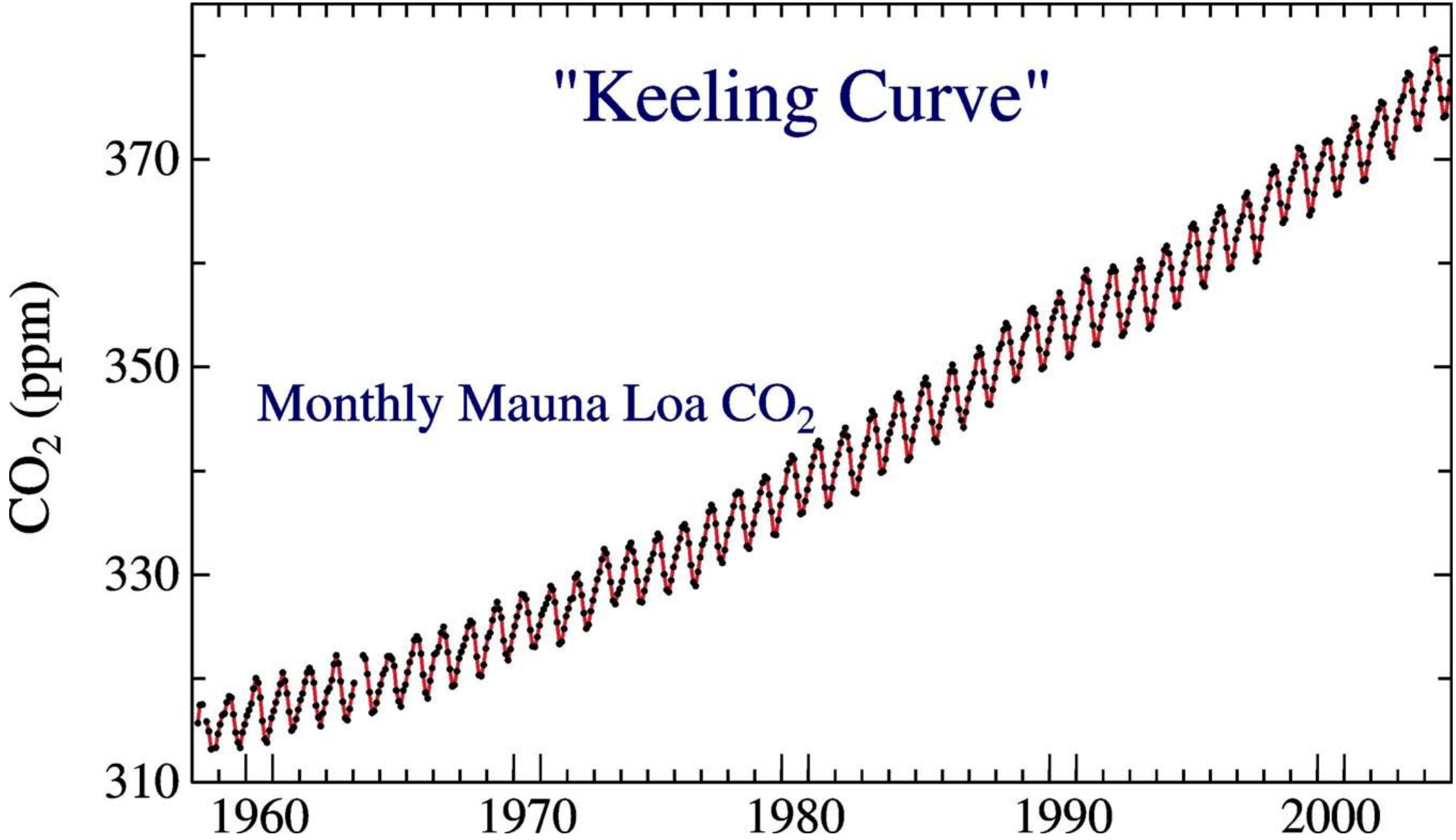
Is There Still Time to Avoid ‘Dangerous Anthropogenic Interference’ with Global Climate?

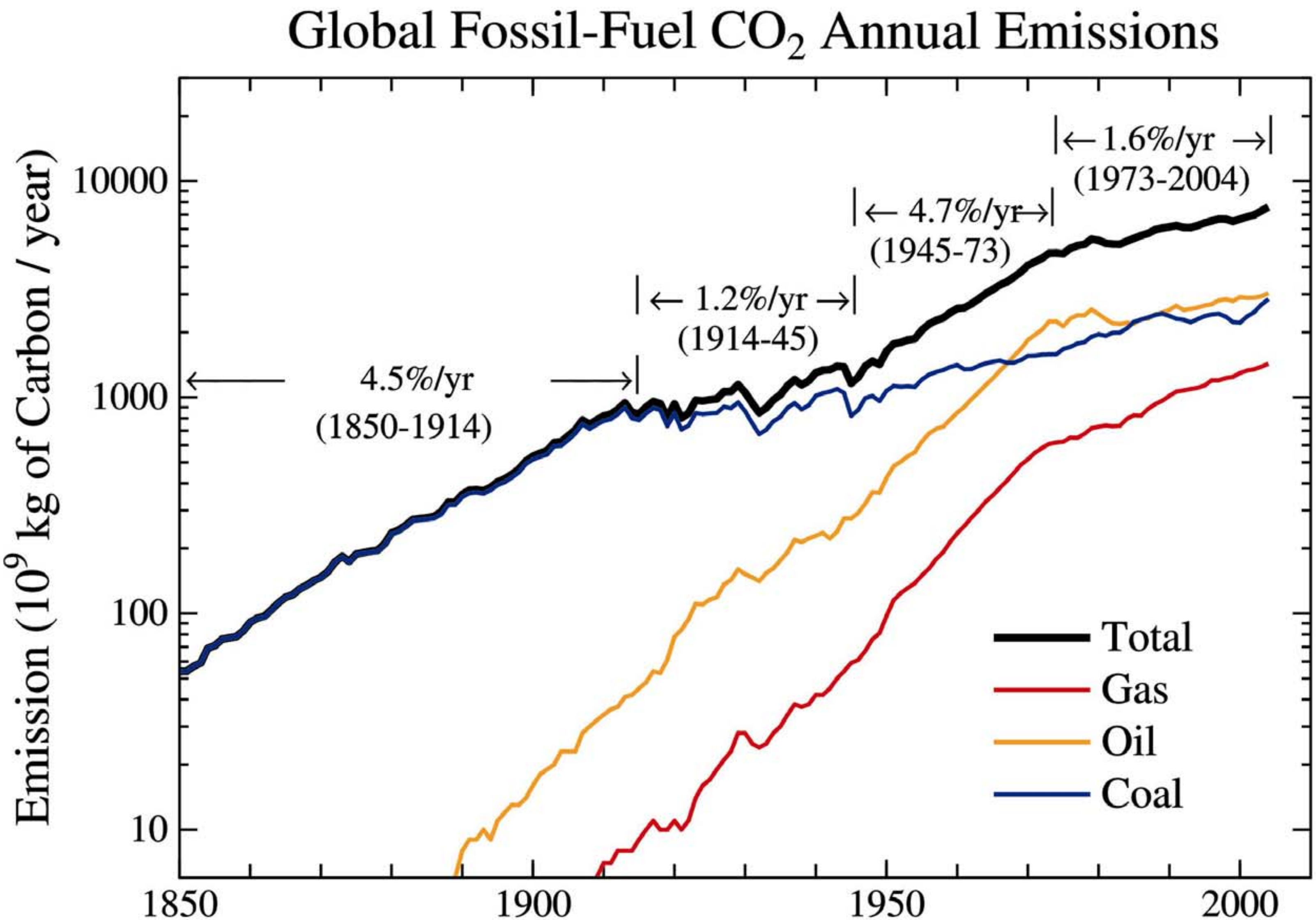
A Tribute to Charles David Keeling

Presentation on 6 December 2005 by James E. Hansen
American Geophysical Union, San Francisco, California



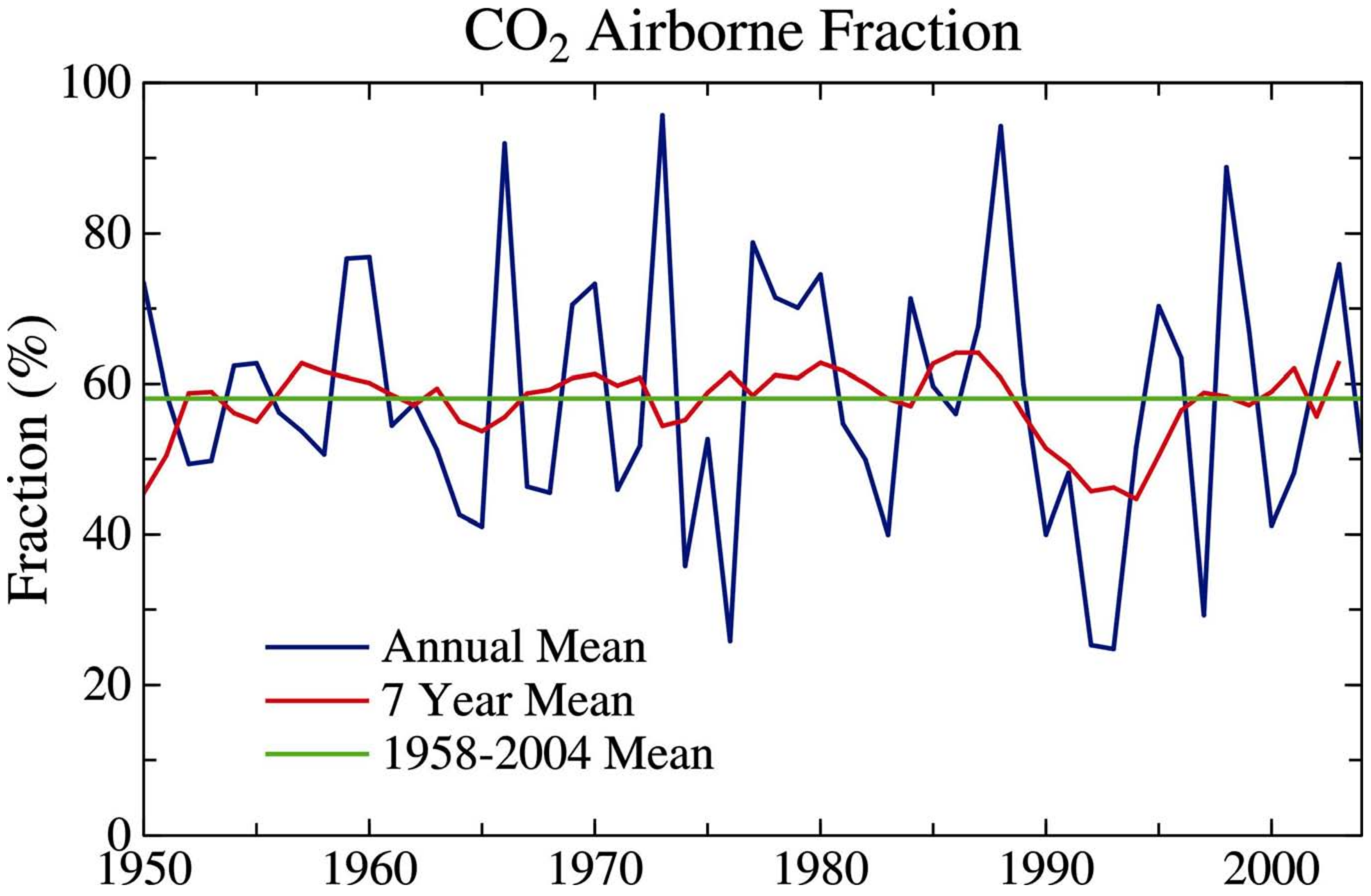
Atmospheric CO_2 measured at Mauna Loa, Hawaii.

Source: NOAA Climate Monitoring and Diagnostic Laboratory



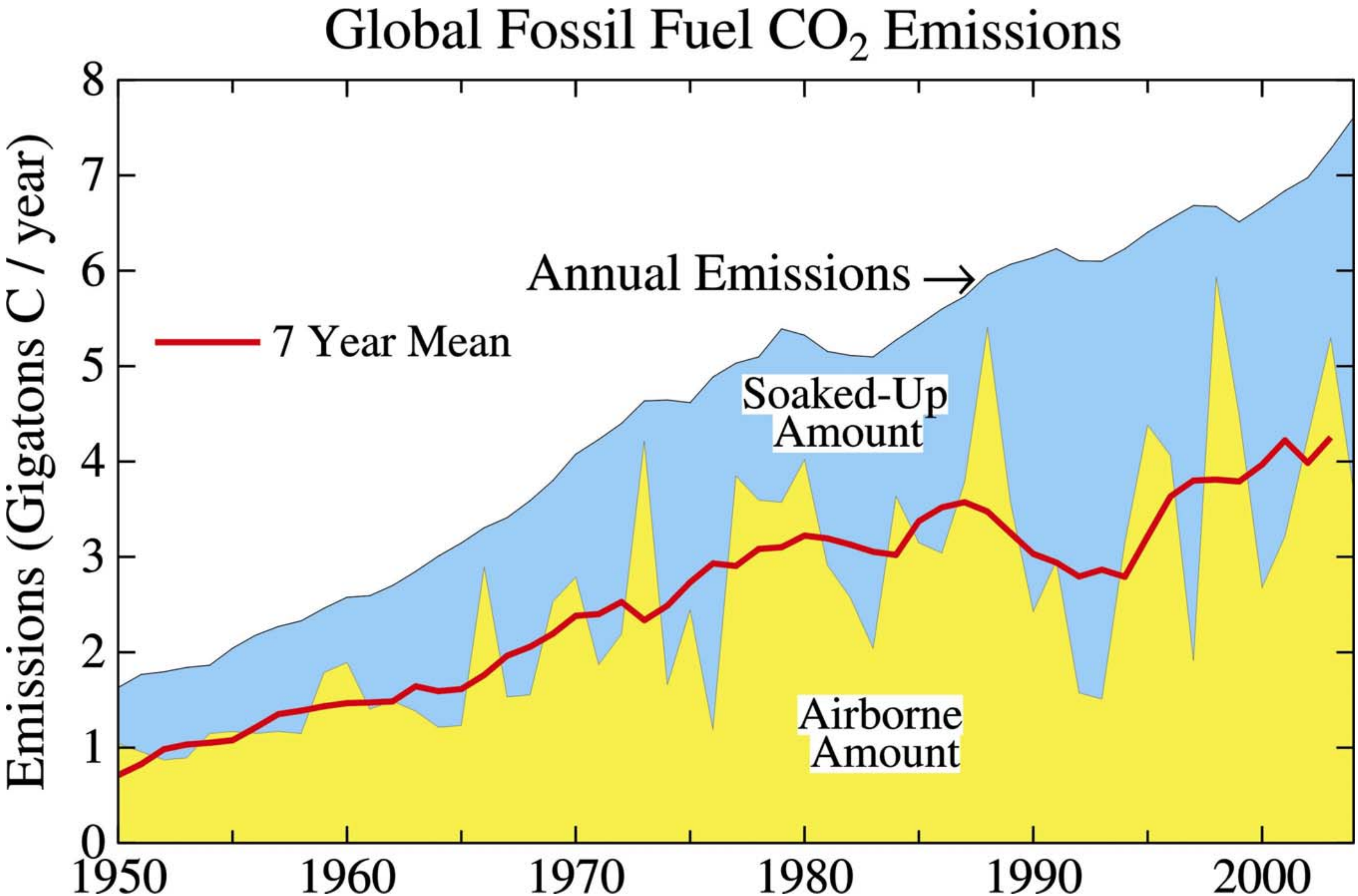
Fossil fuel CO_2 emissions based on data of Marland and Boden (DOE, Oak Ridge) and British Petroleum.

Source: Hansen and Sato, *PNAS,* **98**, 14778, 2001.



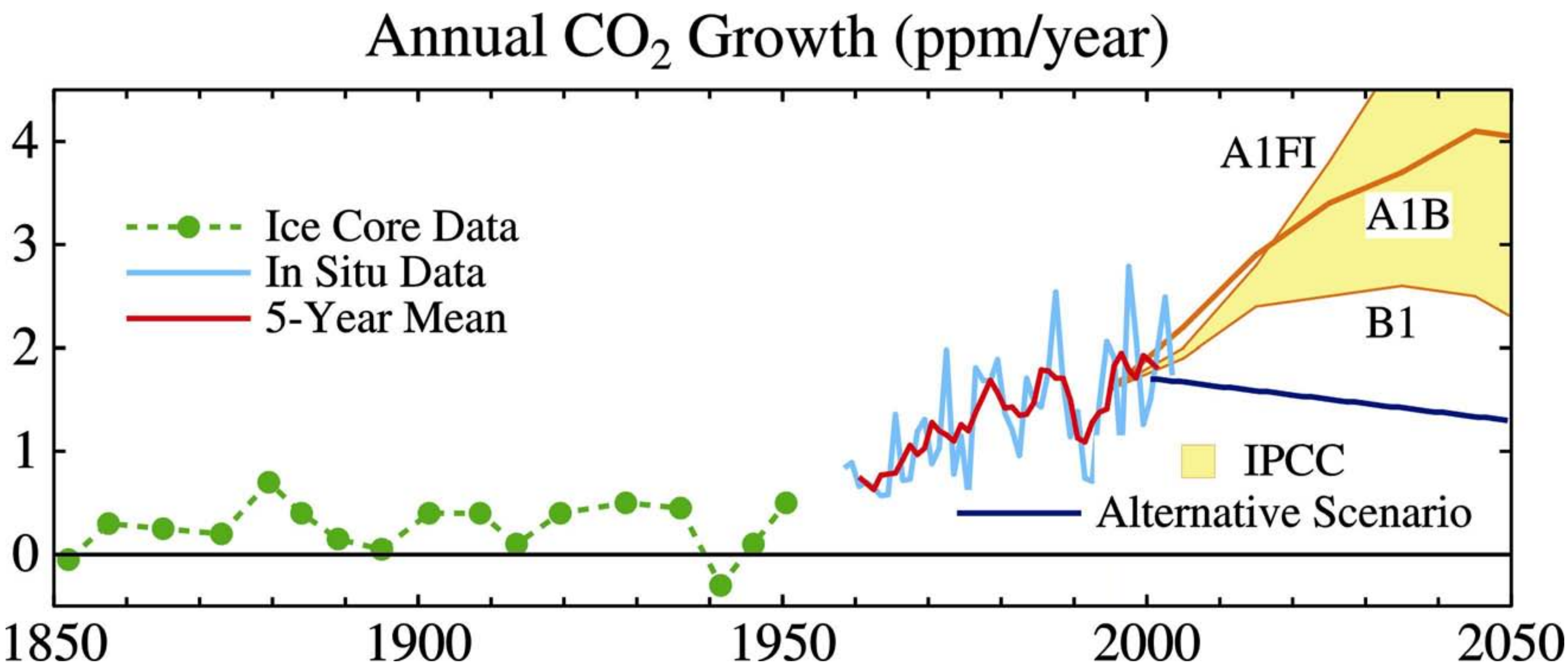
CO_2 airborne fraction, i.e., ratio of annual atmospheric CO_2 increase to annual fossil fuel CO_2 emissions.

Source: Hansen and Sato, *PNAS*, **101**, 16109, 2004.



Global fossil fuel CO_2 emissions with division into portions that remain airborne or are soaked up by the ocean and land.

Source: Hansen and Sato, *PNAS,* **101**, 16109, 2004.



Growth rate of atmospheric CO_2 (ppm/year).

Source: Hansen and Sato, *PNAS,* **101**, 16109, 2004.

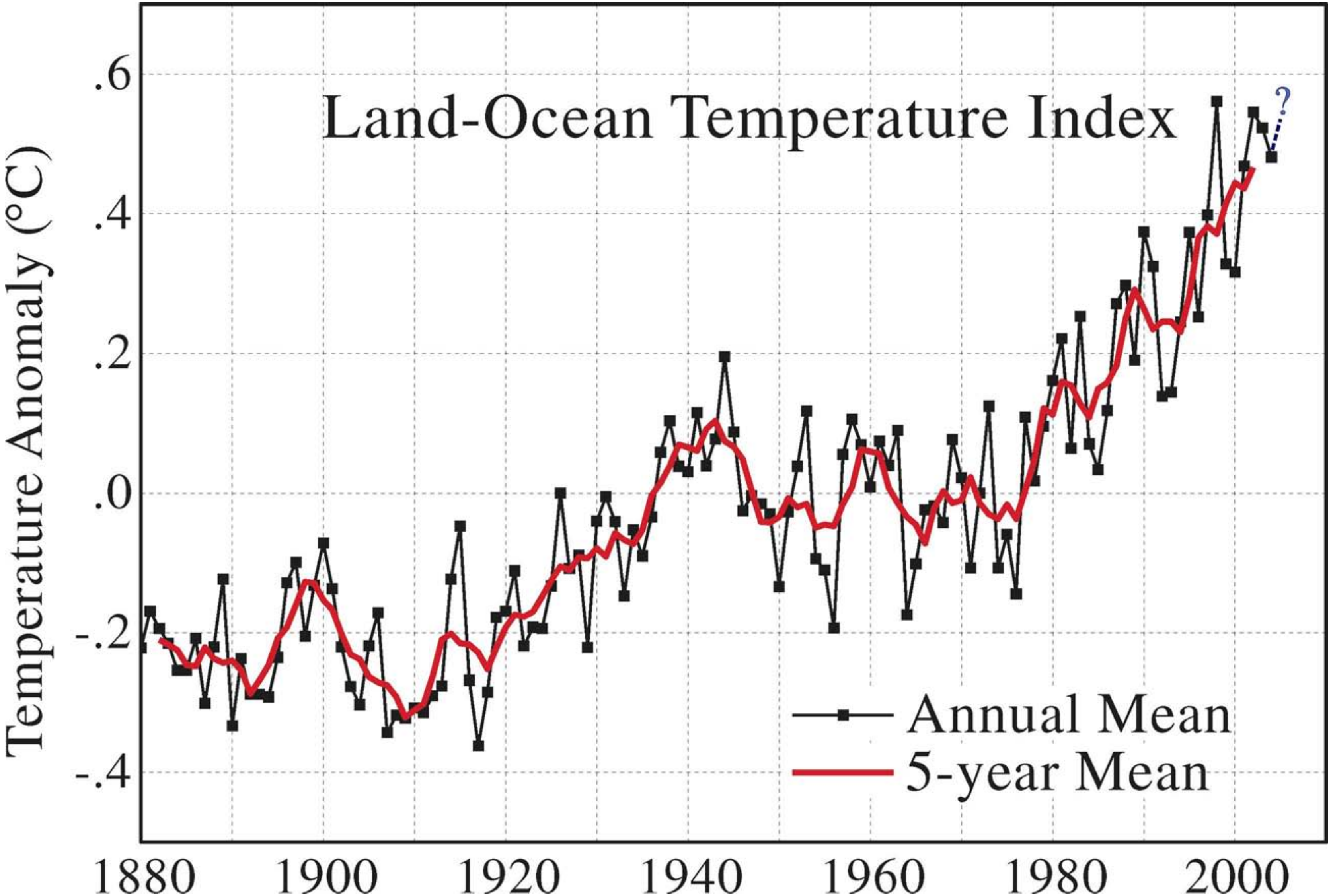
Carbon Dioxide

Good News:

1. ~42% of annual fossil fuel emissions continues to be "soaked up" by ocean, soil, vegetation
2. Uptake % could increase if emissions decreased, or via improved forestation/agricultural practices

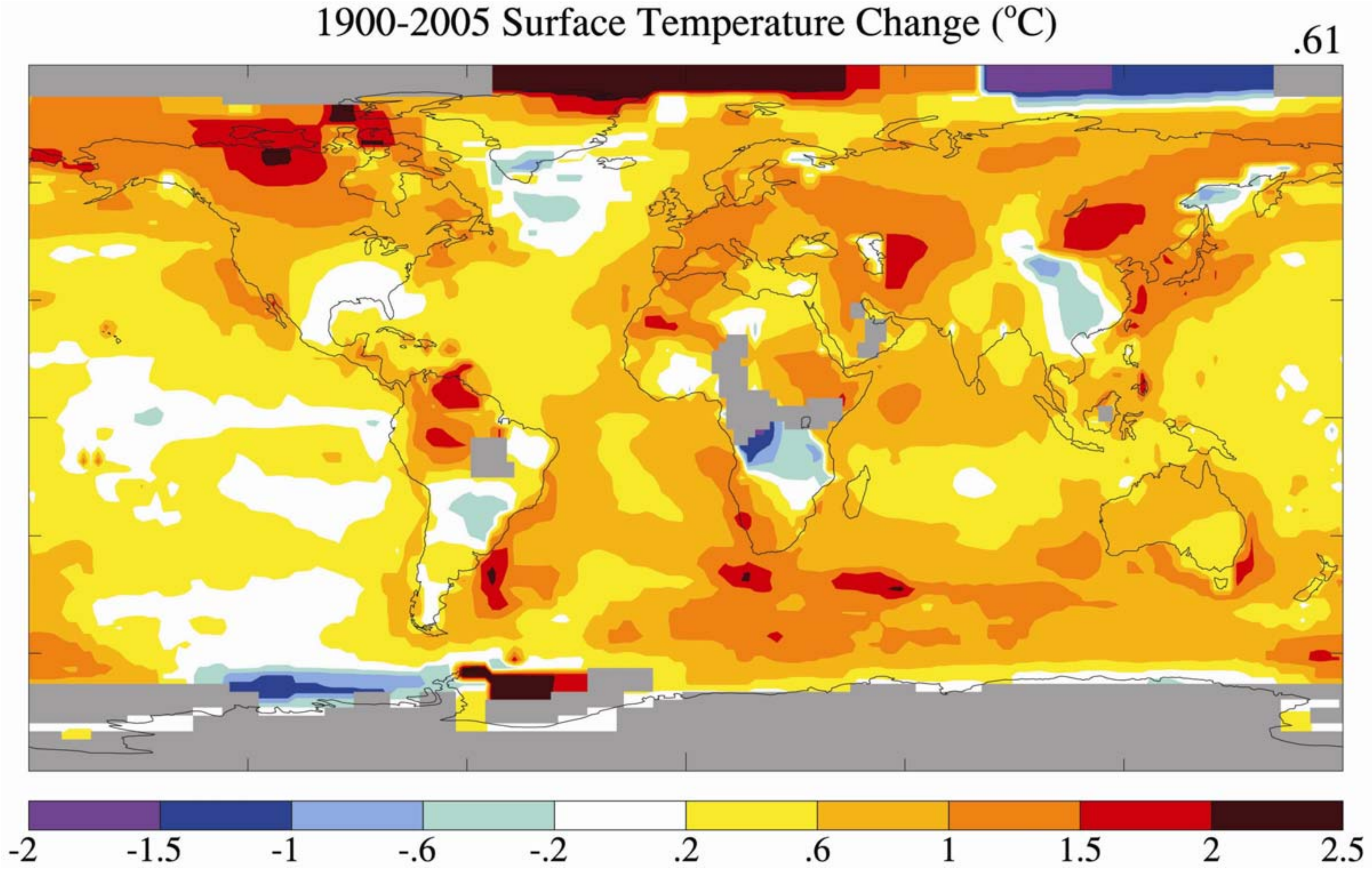
Bad News:

1. Stabilization of atmospheric CO_2 may require eventual reduction of emissions by 60-80%
2. Fossil fuel emission are increasing ~2% per year



Global mean surface temperature change based on surface air measurements over land and SSTs over ocean

Source: Update of Hansen et al., *JGR,* **106**, 23947, 2001; Reynolds and Smith, *J. Climate,* **7**, 1994; Rayner et al., *JGR,* **108**, 2003.



Change of surface temperature index based on local linear trends using surface air temperature over land and SST over ocean.

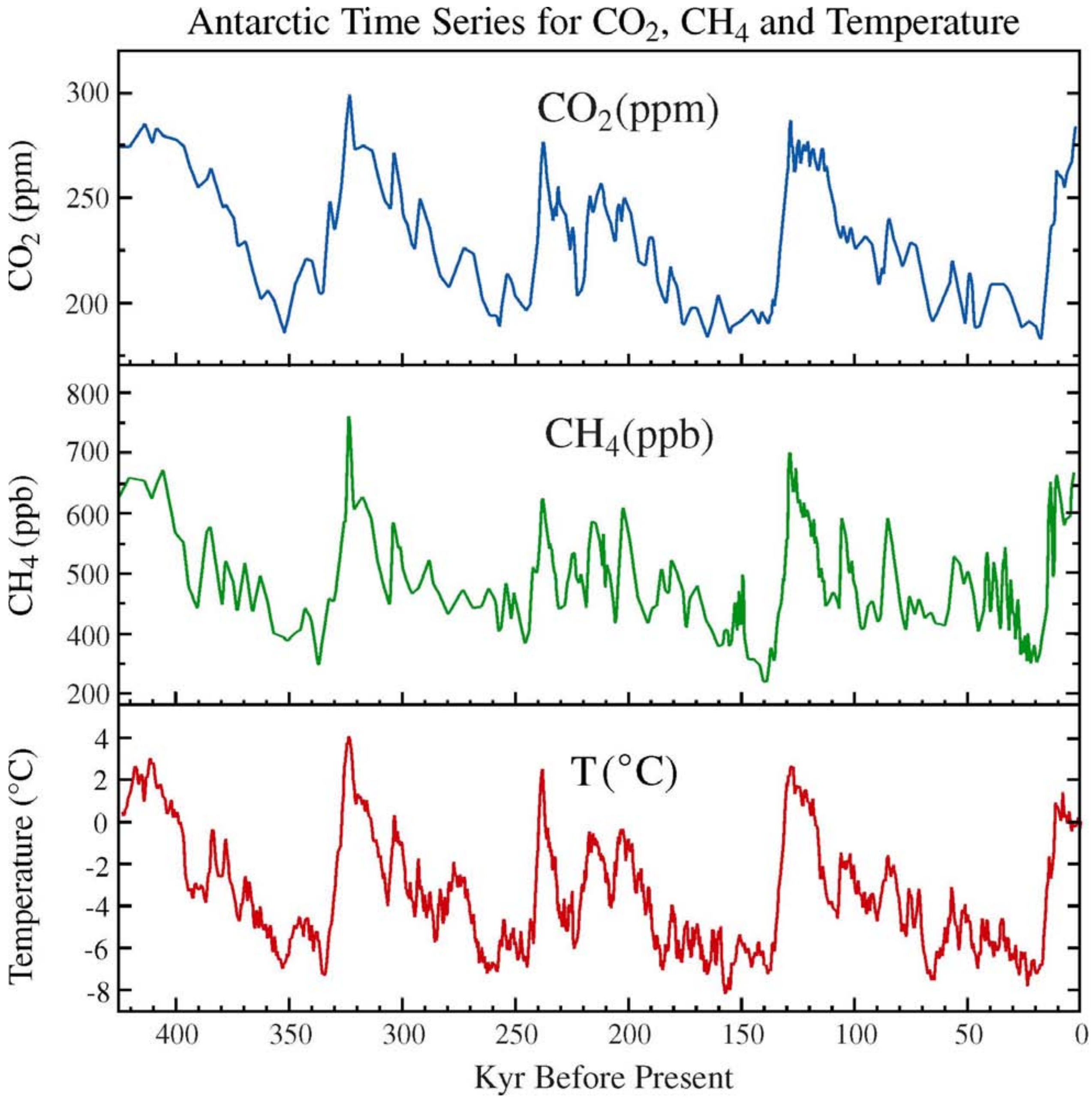
Sources: Hansen et al., *JGR*, **106**, 23947, 2001; Reynolds and Smith, *J. Climate*, **7**, 1994; Rayner et al., *JGR*, **108**, 2003.

Climate Sensitivity

Empirical data

…aided by models…

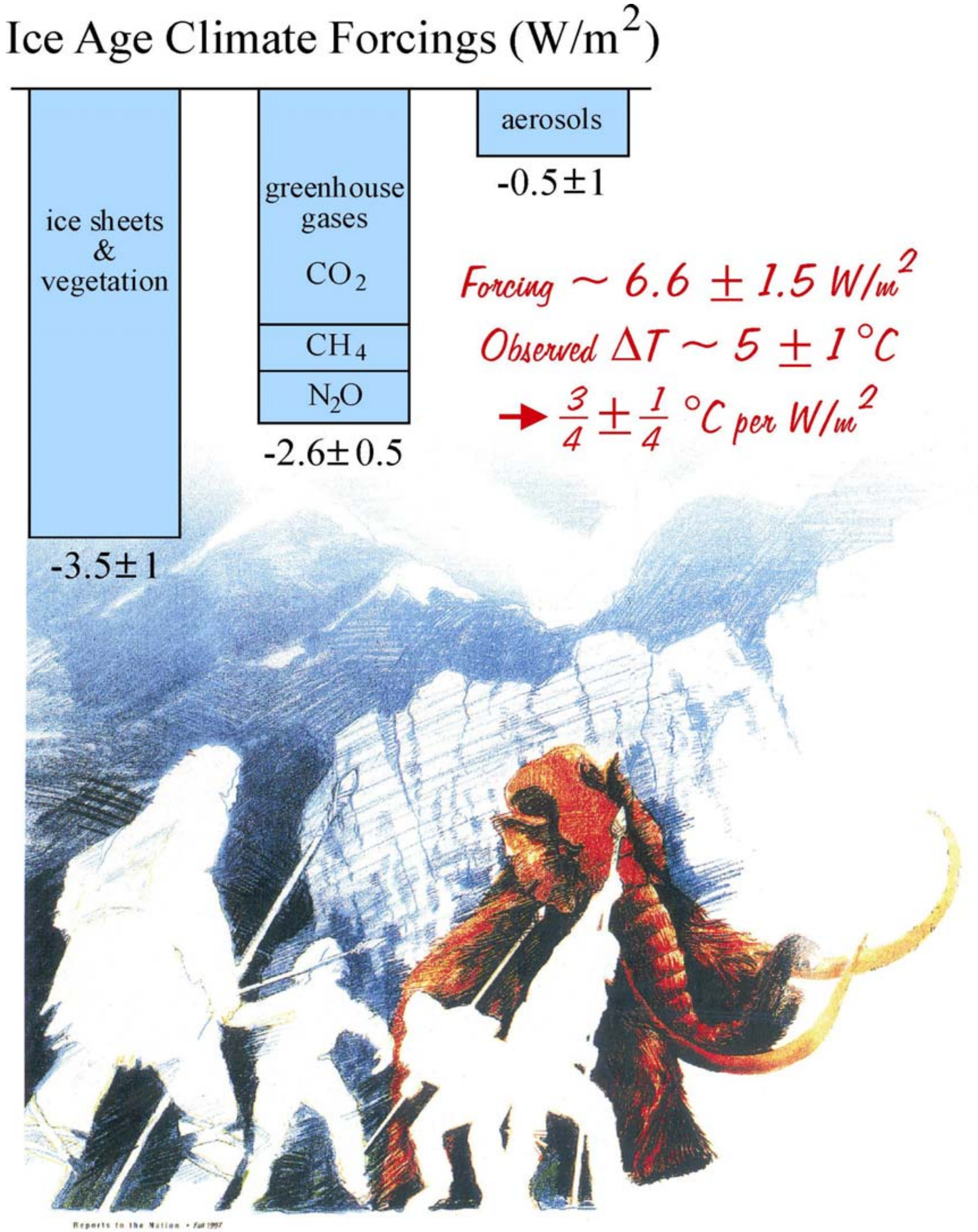
→ precise evaluation



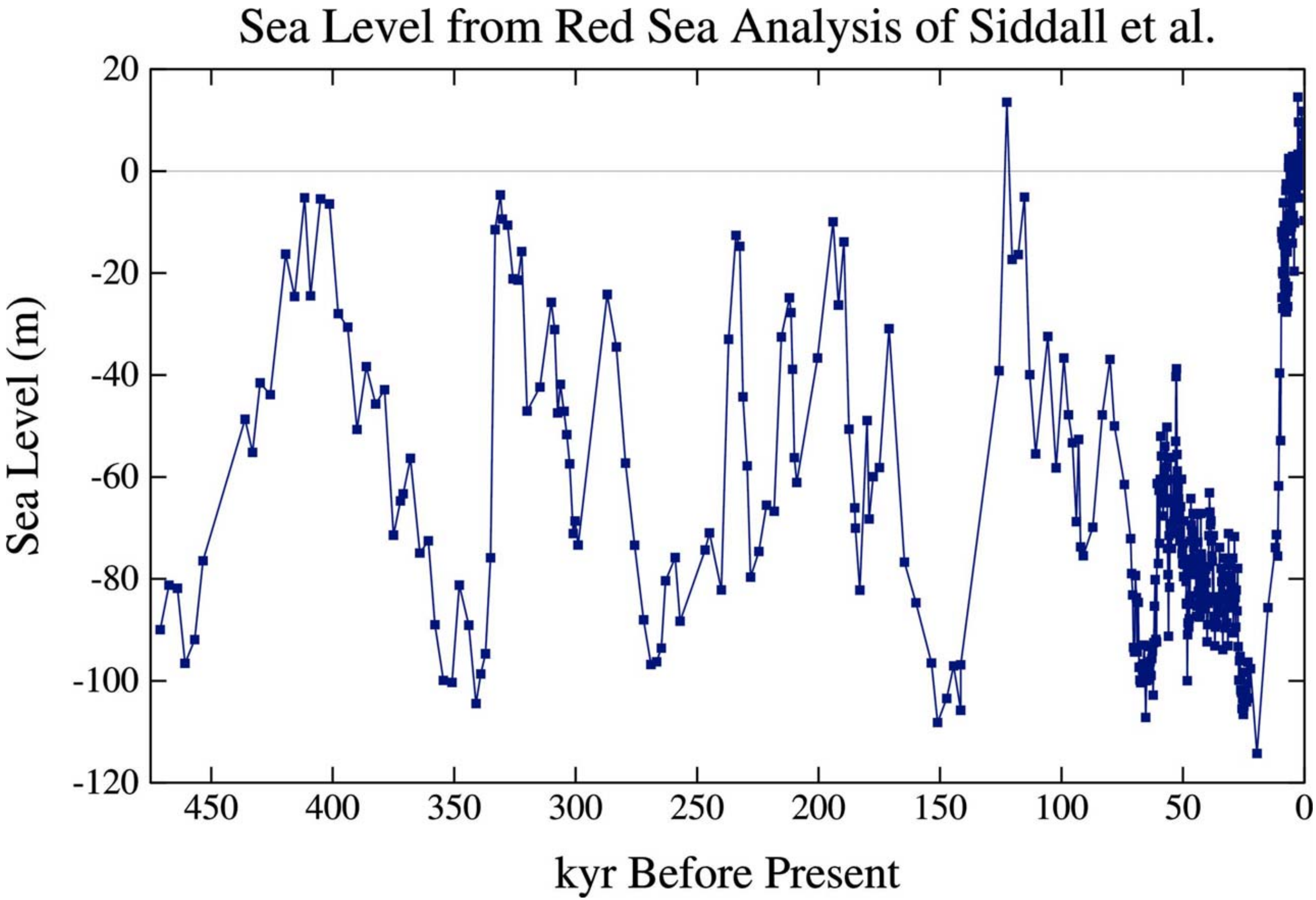
CO_2, CH_4 and temperature records from Antarctic ice core data

Source: Petit et al., Nature, 399, 429, 1999

Ice Age Forcings Imply Global Climate Sensitivity ~ ¾°C per W/m².

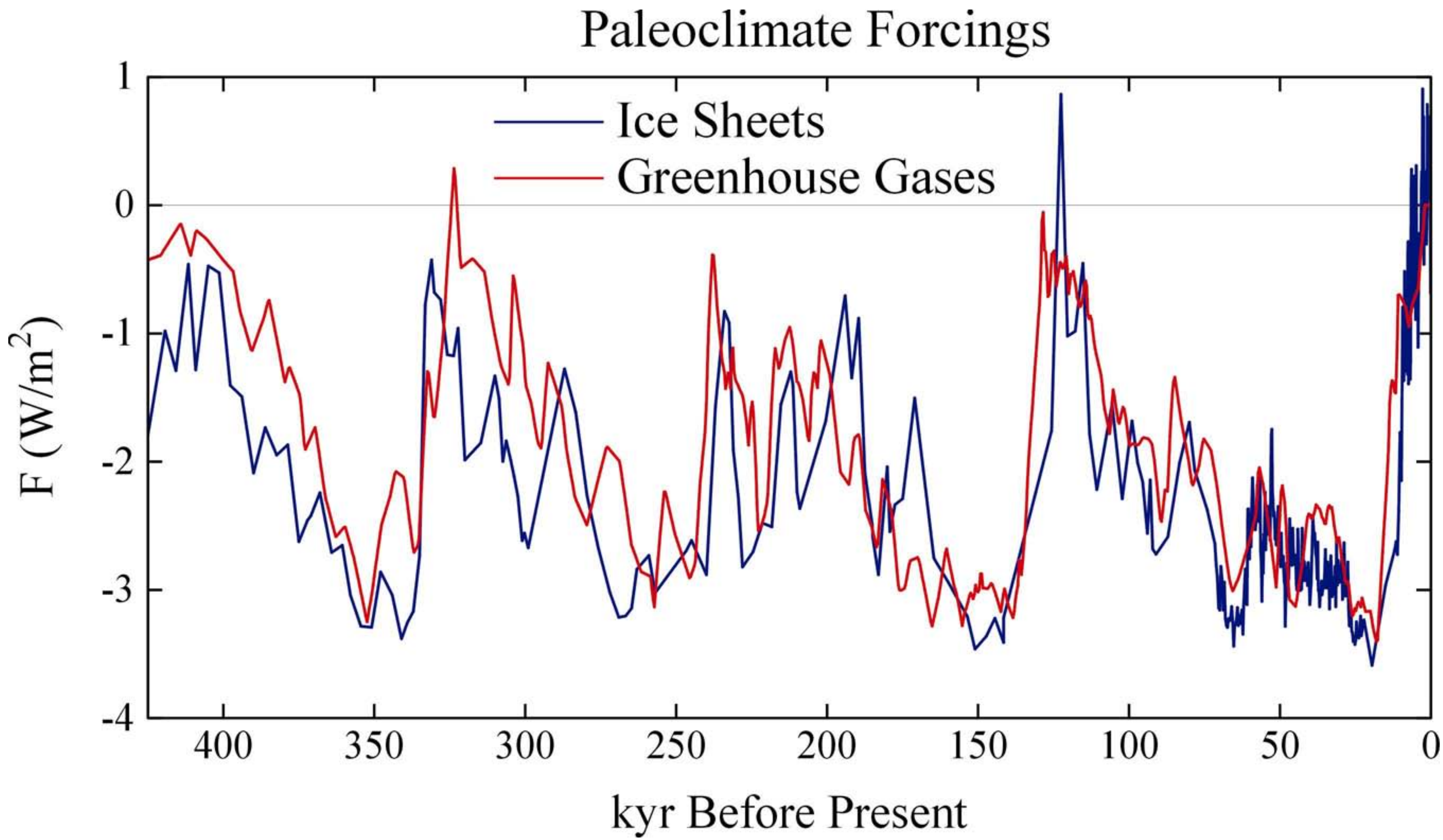


Source: Hansen et al., *Natl. Geogr. Res. & Explor.*, **9**, 141, 1993.

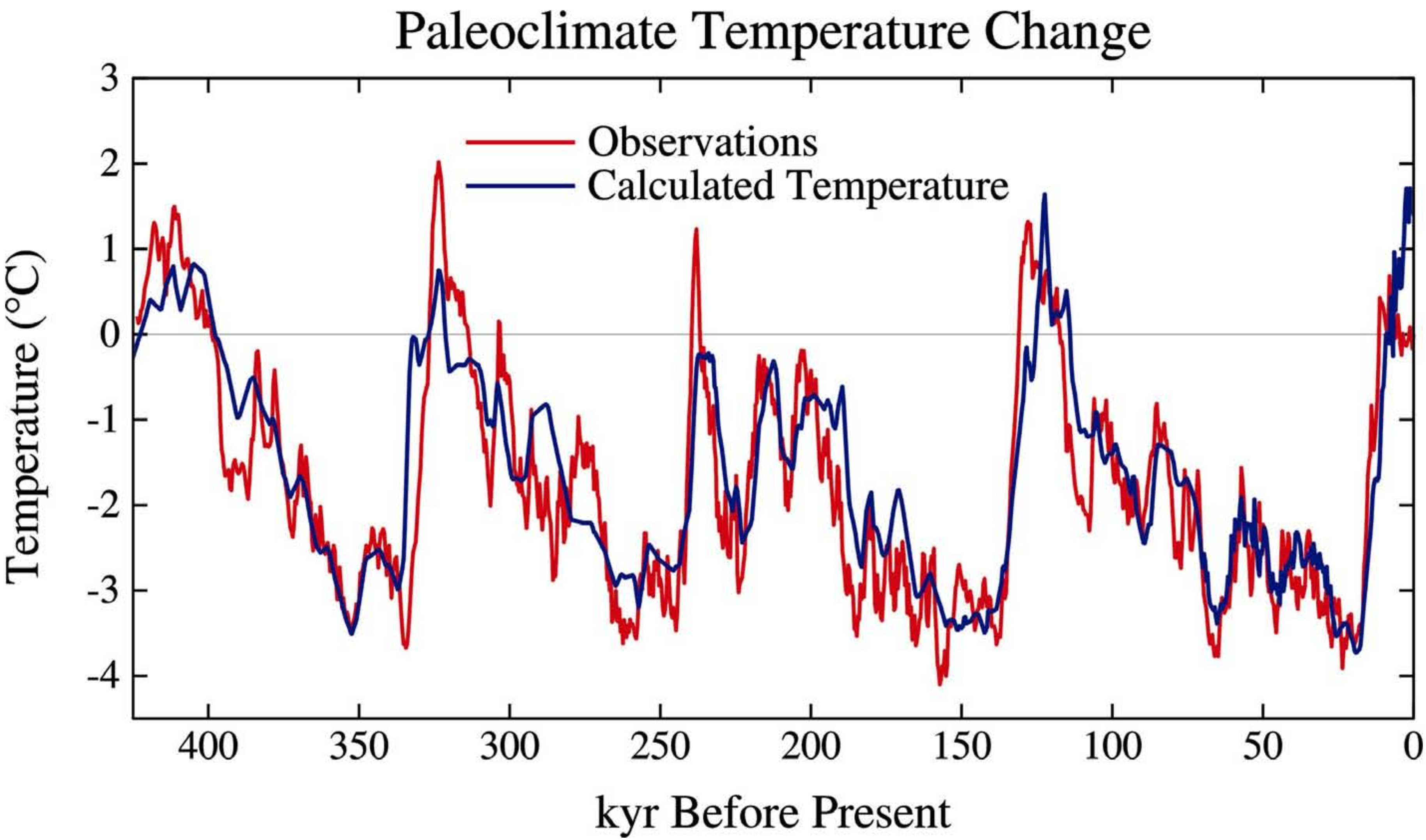


Global sea level extracted, via a hydraulic model, from an oxygen isotope record for the Red Sea over the past 470 kyr (concatenates Siddall's MD921017, Byrd, & Glacial Recovery data sets; AMS radiocarbon dating).

Source: Siddall et al., *Nature*, **423**, 853-858, 2003.

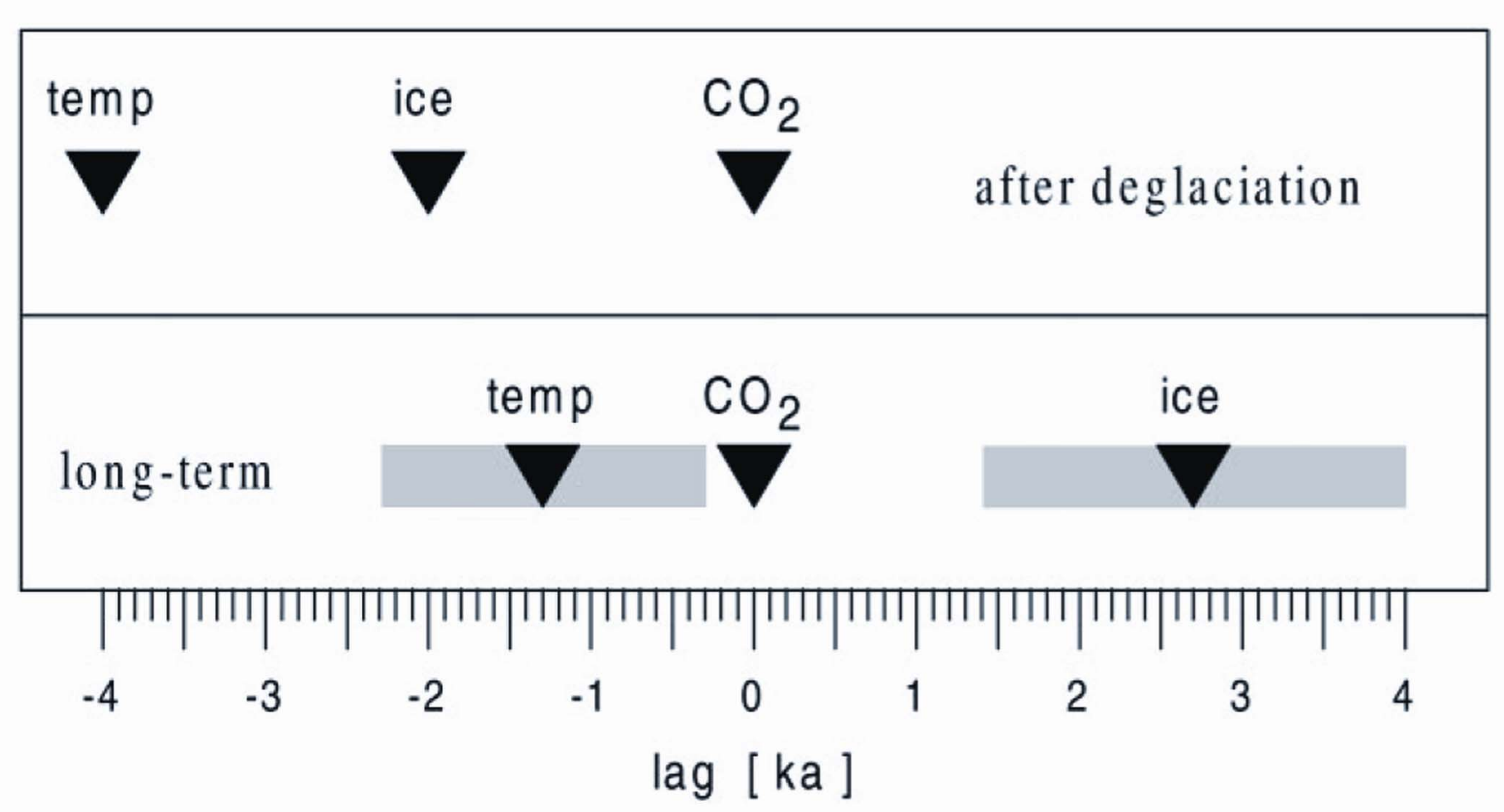


Ice sheet forcing ≅ (sea level)$^{2/3}$
GHGs = CO_2 + CH_4 + N_2O (0.15 forcing of CO_2 + CH_4)



Observations = Vostok ΔT/2.
Calculated temperature = Forcing x 0.75°C /W/m^2

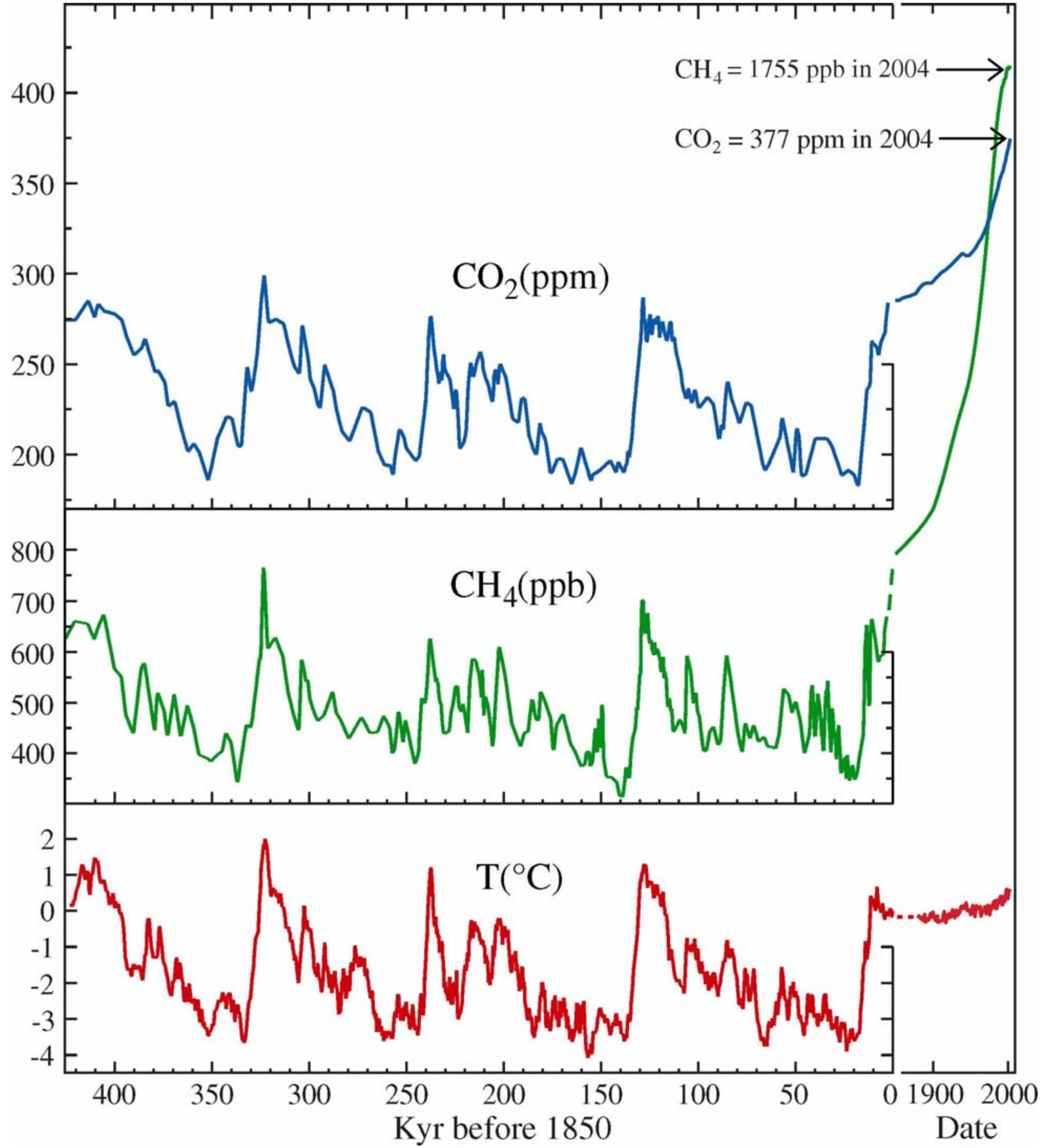
Lag of Global Ice & CO_2 Relative to S.H. Temperature



Leads and lags of Vostok temperature and global ice volume relative to CO_2. Shaded bar is 1σ uncertainty. Temperature and ice are more contemporaneous at some terminations.

Source: M. Mudelsee, Quat. Sci. Rev., **20**, 583, 2001.

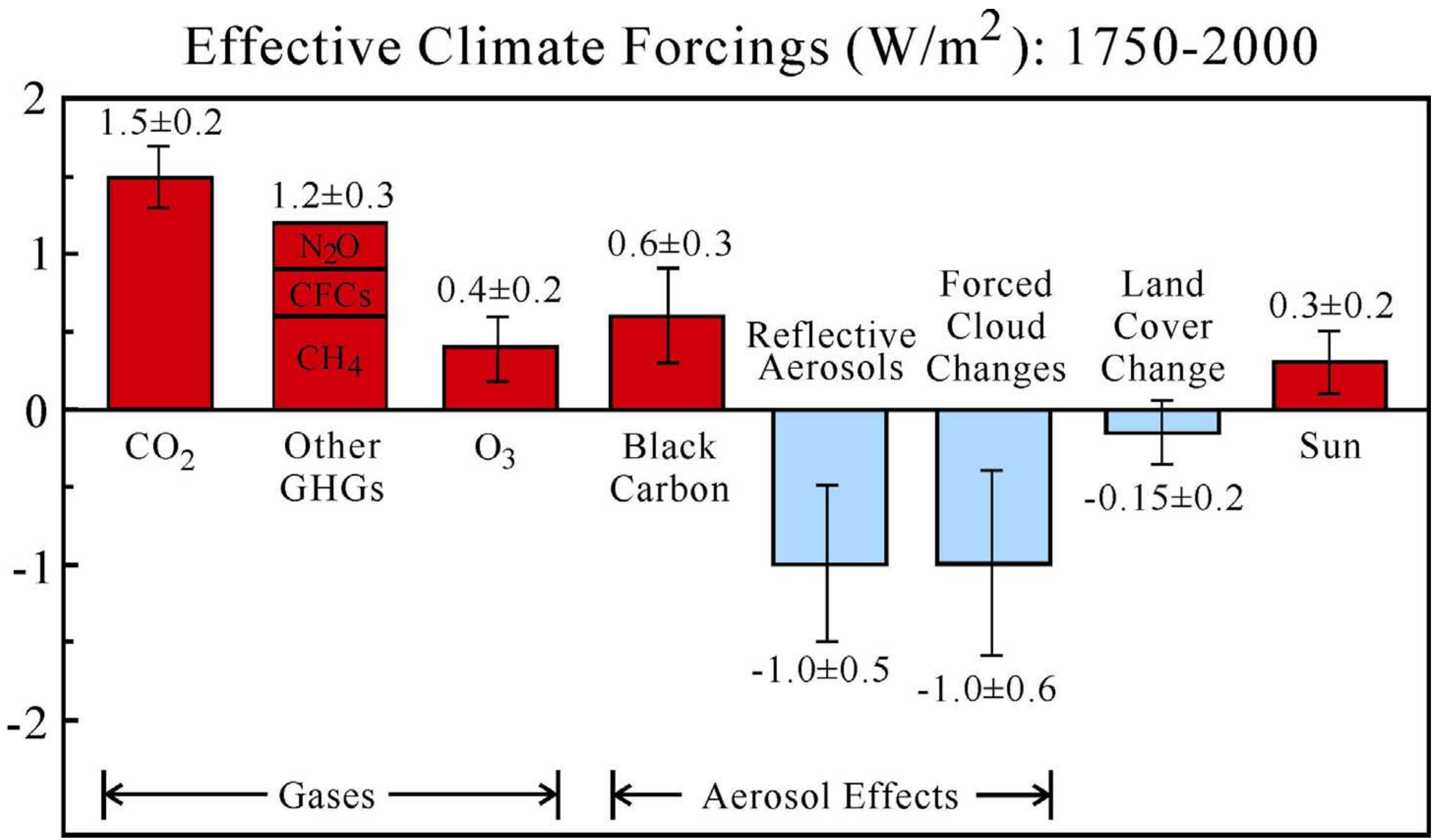
CO_2,CH_4 and estimated global temperature (Antarctic ΔT/2 in ice core era) 0 = 1880-1899 mean.



Source: Hansen, *Clim. Change*, **68**, 269, 2005.

Implications of Paleo Forcings and Response

1. “Feedbacks” (or indirect forcings) cause almost all paleo temperature change.
2. Climate on these time scales is very sensitive to even small forcings.
3. Instigators of climate change must include: orbital variations, other small forcings, noise.
4. Another “ice age” cannot occur unless humans become extinct. Even then, it would require thousands of years. Humans now control global climate, for better or worse.



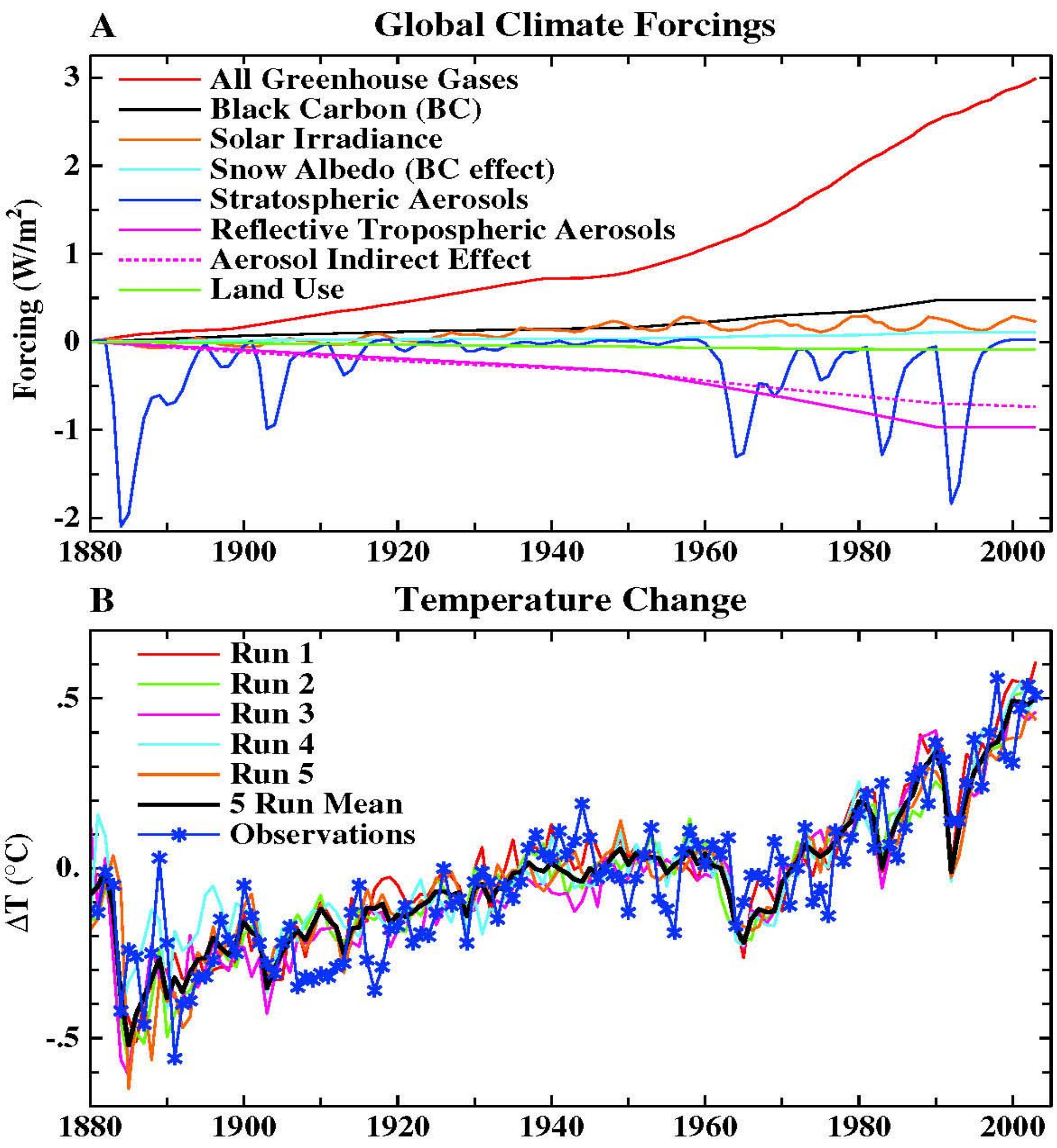
Climate forcing agents in the industrial era. "Effective" forcing accounts for "efficacy" of the forcing mechanism

Source: Hansen et al., JGR, **110**, D18104, 2005.

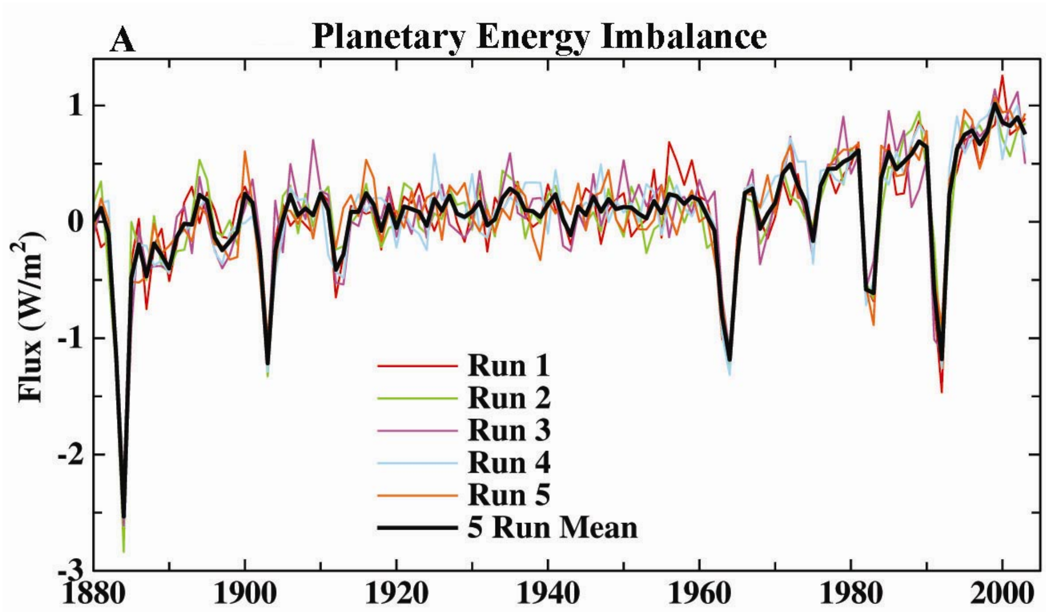
(A) Forcings used to drive climate simulations.

(B) Simulated and observed surface temperature change.

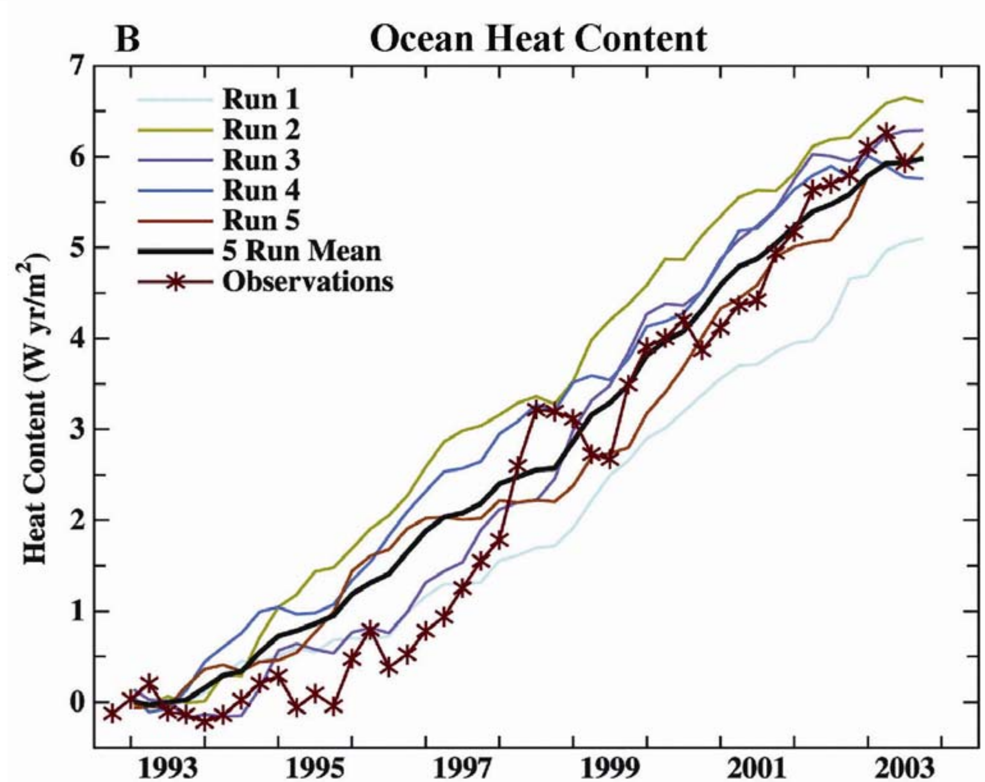
Source: Earth's energy imbalance: Confirmation and implications. *Science* **308**, 1431, 2005.



(A) Net Radiation at top of atmosphere in climate simulations.



(B) Ocean heat gain in the top 750 m of world ocean.



Source: Hansen et al., Science, **308**, 1431, 2005.

Consistency Check

1.85 W/m^2 = 1880-2003 forcing

1.00 W/m^2 = used for observed 2/3°C warming

0.85 W/m^2 = remains, not yet responded to

Implications

1. 0.6°C more warming in the pipeline

2. Confirms climate system lag

→ Need anticipatory actions to avoid any specified level of "dangerous" change

3. Acceleration of sea level rise is likely

Source: Hansen et al., *Science*, **308**, 1431, 2005.

United Nations
Framework Convention on Climate Change

Aim is to stabilize greenhouse gas emissions…

"…at a level that would prevent dangerous anthropogenic interference with the climate system."

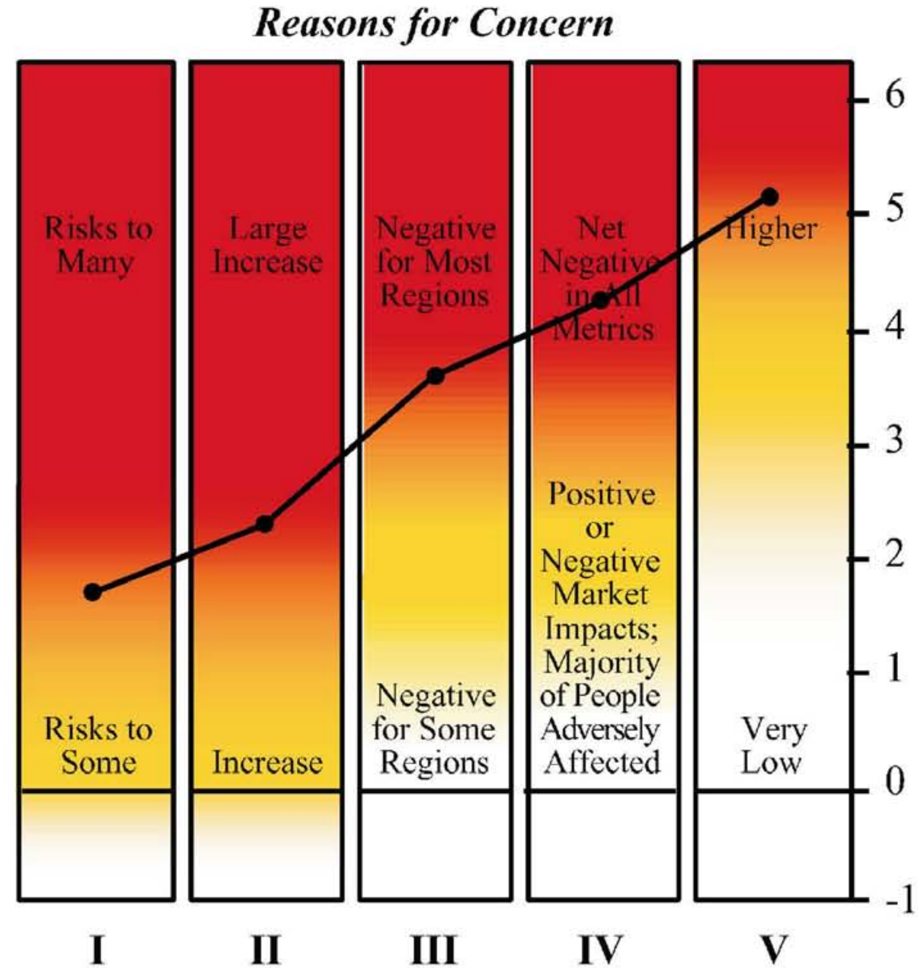
IPCC Burning Embers

White: neutral or small positive or negative impacts

Yellow: negative impacts for some systems or low risks

Red: negative impacts or risks that are more widespread and/or greater in magnitude

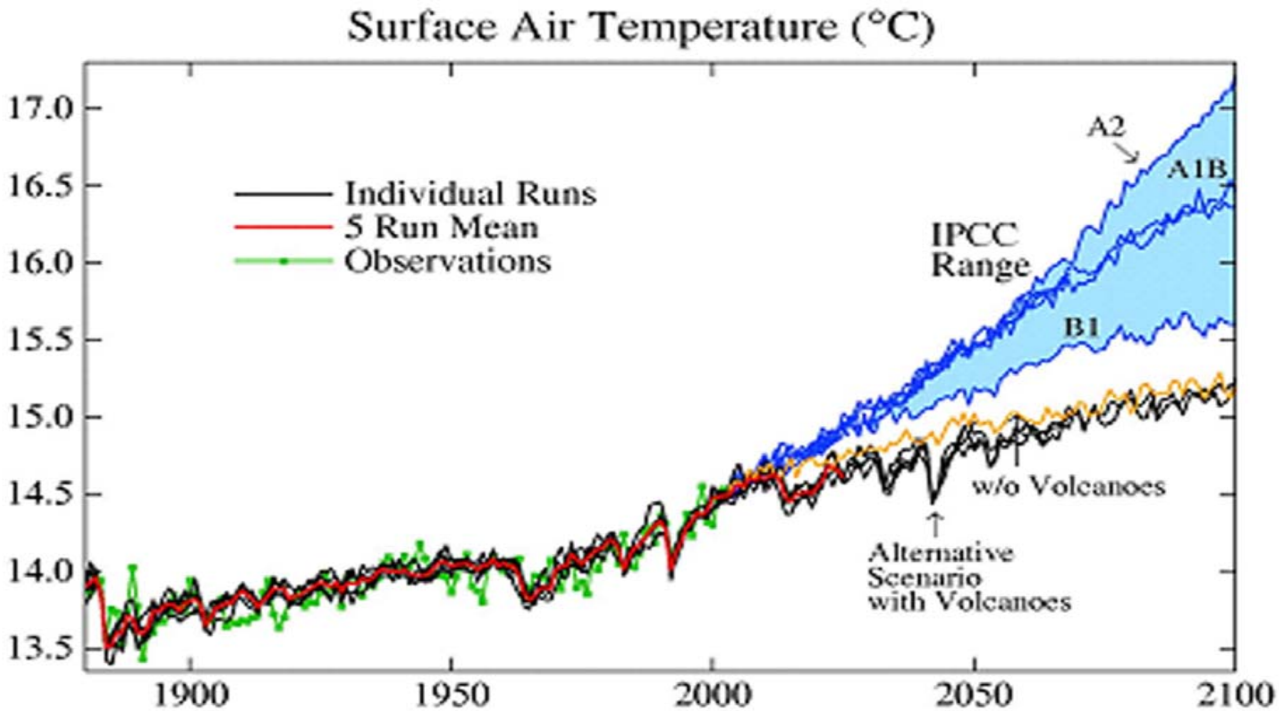
I	Risks to Unique and Threatened Systems
II	Risks from Extreme Climate Events
III	Distribution of Impacts
IV	Aggregate Impacts
V	Risks from Future Large-Scale Discontinuities



Reasons for concern about projected climate change impacts

Source: IPCC *Climate Change 2001;* S. Schneider & M. Mastrandrea, *PNAS,* **102**, 15728, 2005.

21st Century Global Warming



Climate Simulations for IPCC 2007 Report

► **Climate Model Sensitivity ~ 2.7°C for 2xCO_2**
(consistent with paleoclimate data & other models)

► **Simulations Consistent with 1880-2003 Observations**
(key test = ocean heat storage)

► **Simulated Global Warming < 1°C in Alternative Scenario**

Conclusion: Warming < 1°C if additional forcing ~ 1.5 W/m²

Source: Hansen et al., *to be submitted to J. Geophys. Res.*

Metrics for "Dangerous" Change

Physical Climate System Approach

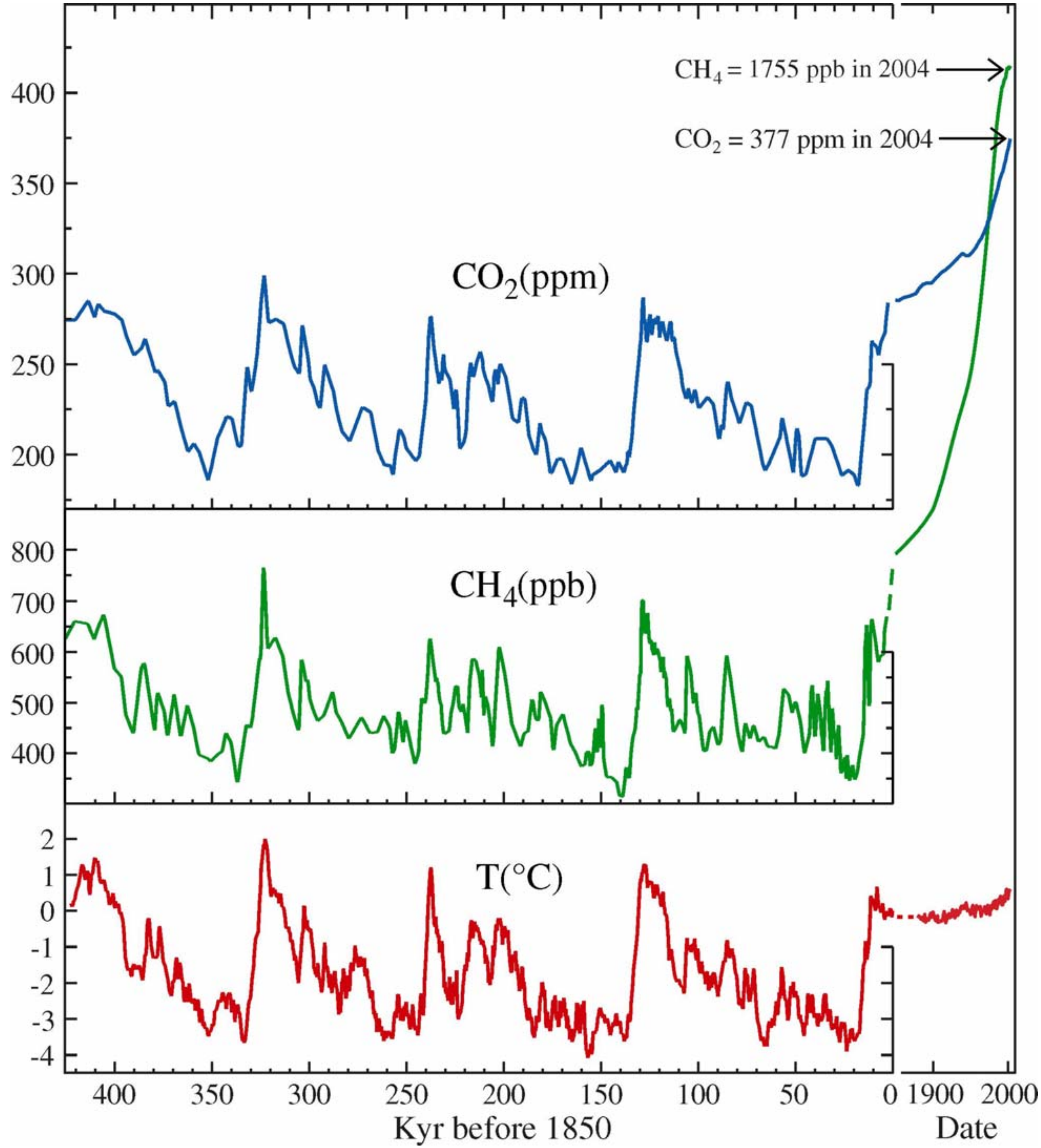
Global Sea Level

1. Long-Term Change: Paleoclimate Data
2. Ice Sheet Response Time

Regional Climate Change

1. General Statement
2. Specific Cases

CO_2,CH_4 and estimated global temperature (Antarctic ΔT/2 in ice core era) 0 = 1880-1899 mean.



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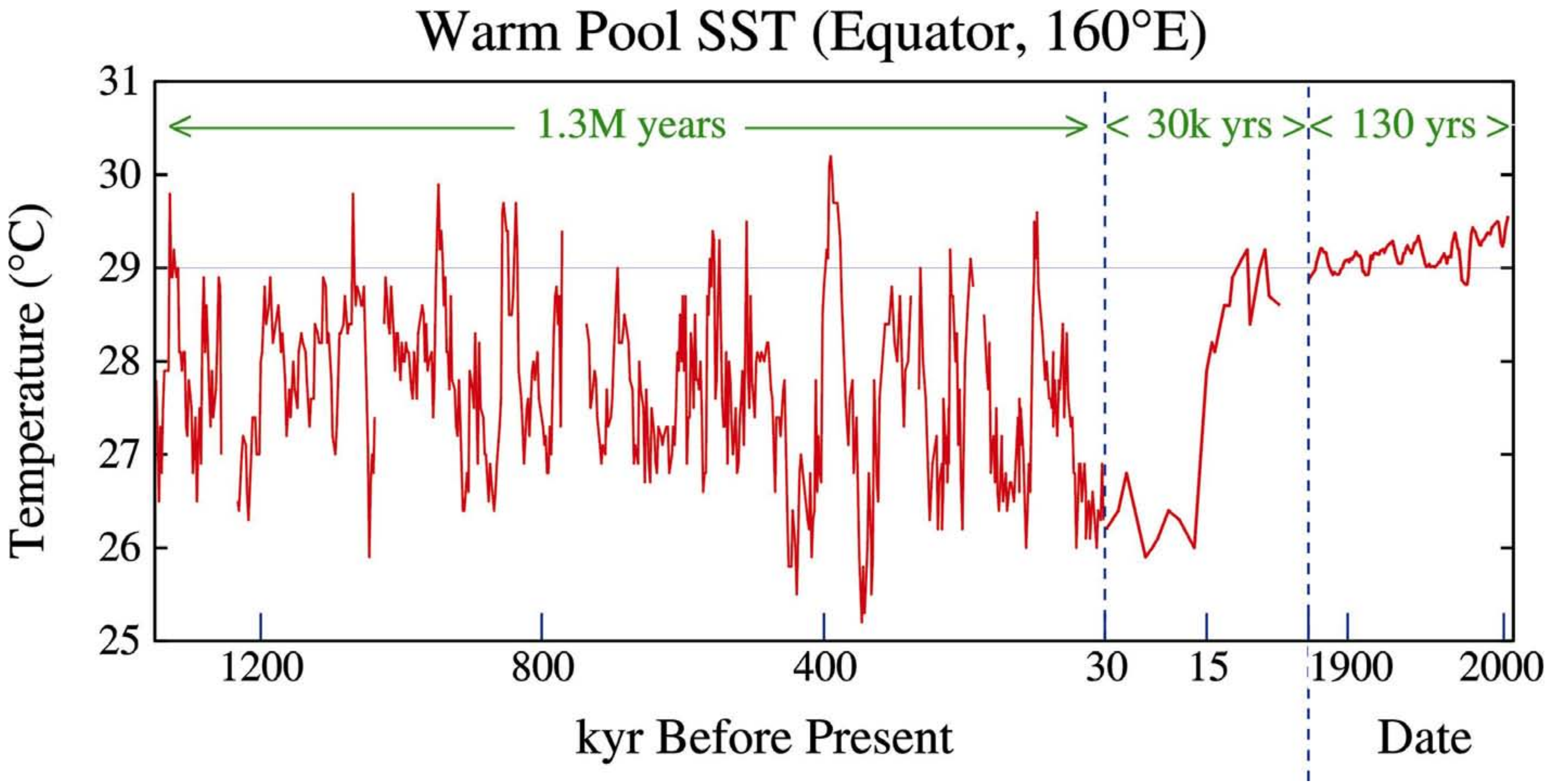


SST in Pacific Warm Pool (ODP site 806B, 0°N, 160°E) in past millennium. Time scale expanded in recent periods. Data after 1880 is 5-year mean.

Source: Medina-Elizalde and Lea, ScienceExpress, 13 October 2005;data for 1880-1981 based on Rayner et al., *JGR*, **108**, 2003, after 1981 on Reynolds and Smith, *J. Climate*, **7**, 1994.

Ice Sheet Response Time:
Millennia or Centuries?

1. **Paleoclimate Data**

    Dated "Terminations"

    ~10 m "Sub-orbital" Sea Level Change

2. **Satellite & Field Data**

    Linear Growth, Nonlinear Disintegration

3. **Ice Sheet Models**

    Fail paleoclimate & satellite tests

Paleoclimate Sea Level Data

1. Rate of Sea Level Rise

- Data reveal numerous cases of rise of several m/century (e.g., MWP 1A)

2. "Sub-orbital" Sea Level Changes

- Data show rapid changes ~ 10 m within interglacial & glacial periods

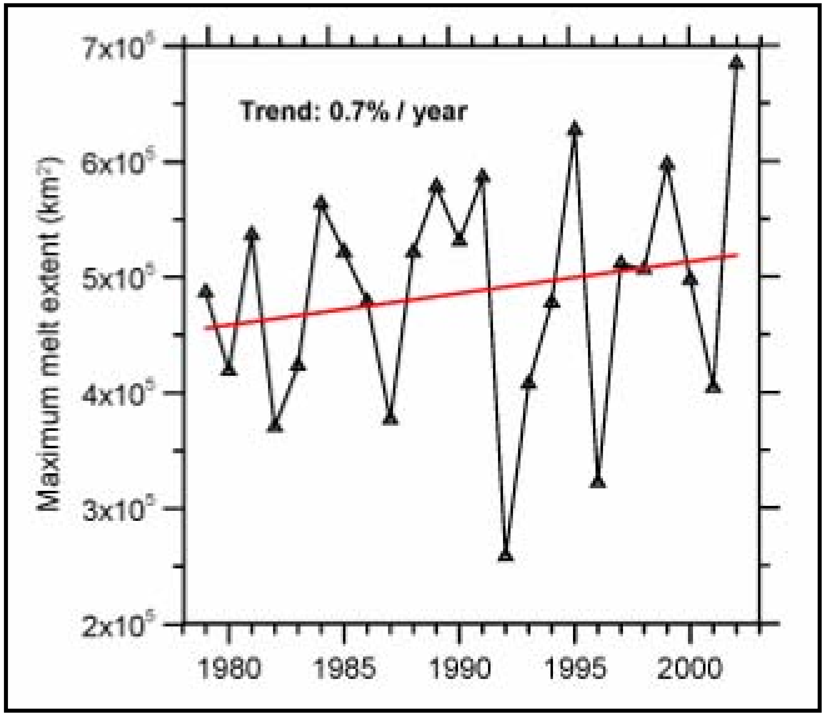
Ice Sheet Models Do Not Produce These

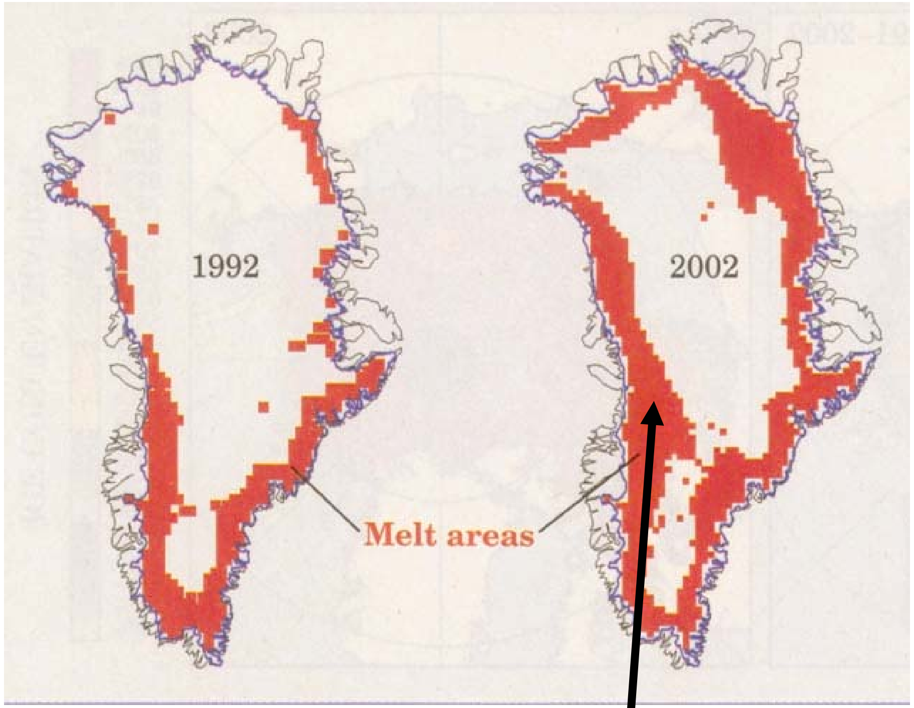
Surface Melt on Greenland

Melt descending
into a moulin,
a vertical shaft
carrying water
to ice sheet base.

Source: Roger Braithwaite,
University of Manchester (UK)

Increasing Melt Area on Greenland





- 2002 all-time record melt area
- Melting up to elevation of 2000 m
- 16% increase from 1979 to 2002

70 meters thinning in 5 years

Satellite-era record melt of 2002 was exceeded in 2005.

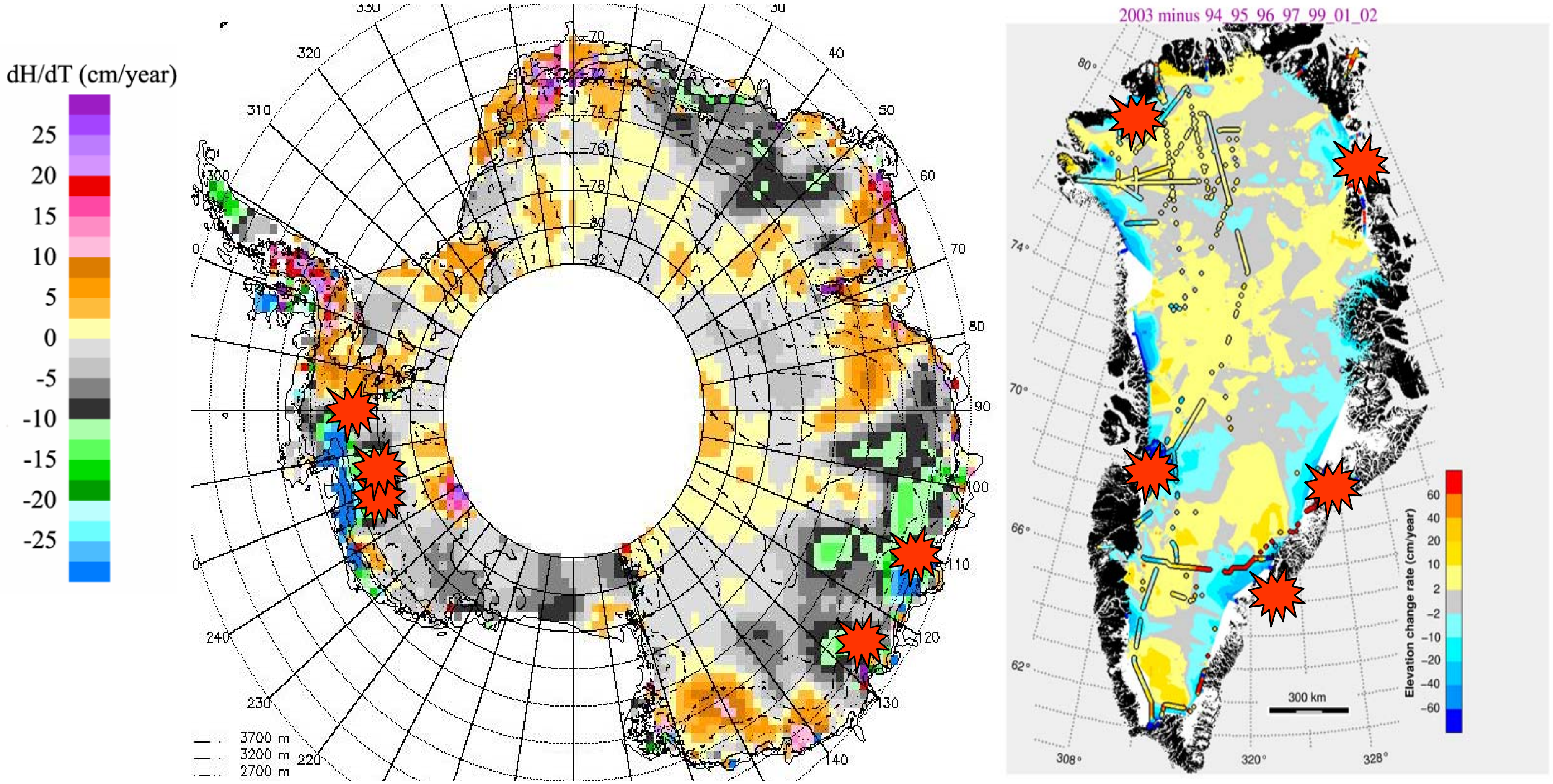
Source: Waleed Abdalati, Goddard Space Flight Center

Jakobshavn Ice Stream in Greenland

Discharge from major Greenland ice streams is accelerating markedly.

Source: Prof. Konrad Steffen, Univ. of Colorado

Satellites Reveal Changing Ice Sheets



Rapid thinning is concentrated at outlet glaciers exiting deep (sub sea level) valleys

Source: Robert Bindschadler, Goddard Space Flight Center

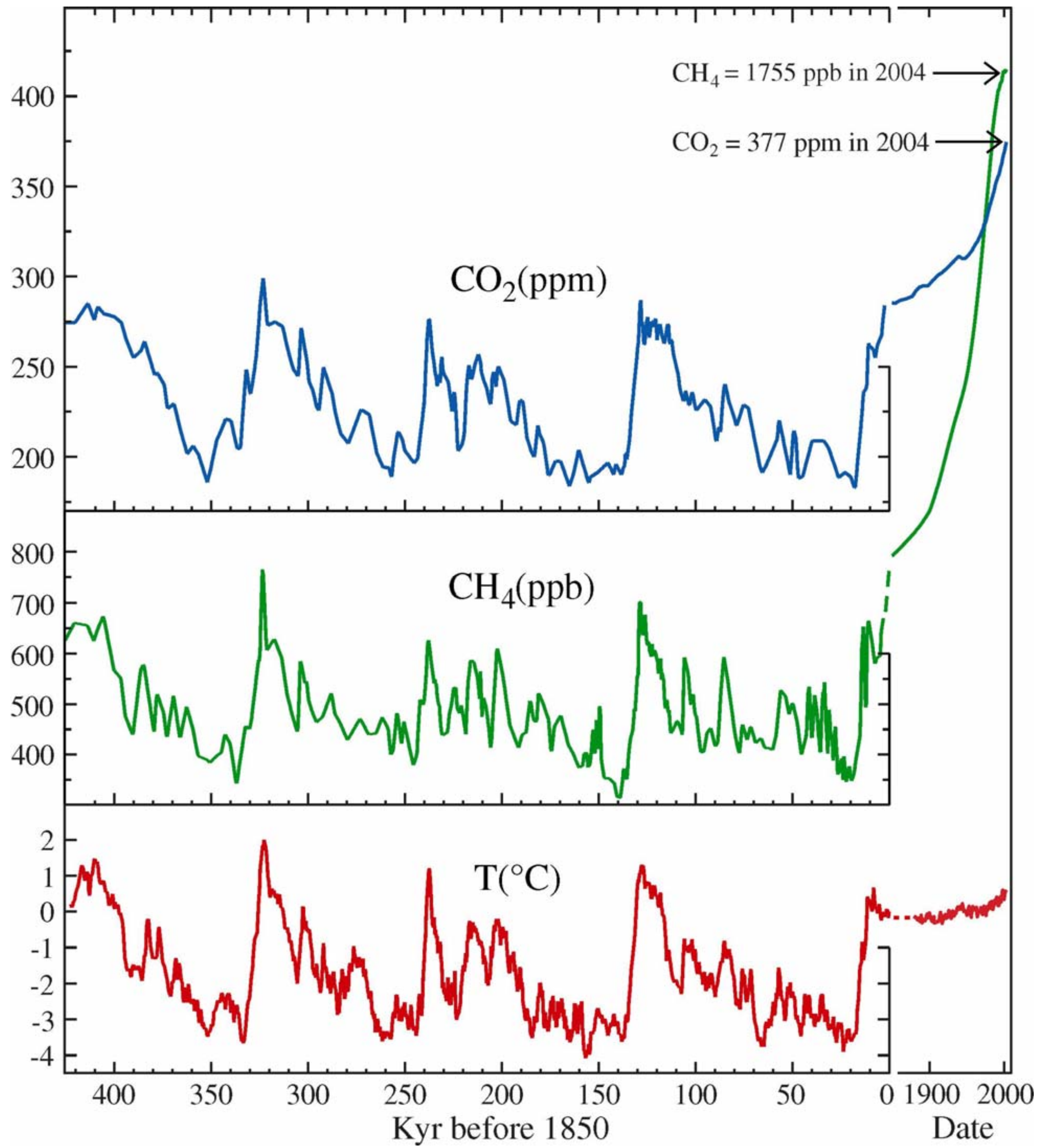
Summary: Ice Sheets

1. Human Forcing Dwarfs Paleo Forcing

2. Sea Level Rise Starts Slowly as Interior Ice Sheet Growth Temporarily Offsets Ice Loss at the Margins

3. Equilibrium Sea Level Response for ~3C Warming (25±10 m = 80 feet) Implies Potential for a System Out of Our Control

CO_2,CH_4 and estimated global temperature (Antarctic ΔT/2 in ice core era)
0 = 1880-1899 mean.



Source: Hansen, *Clim. Change*, **68**, 269, 2005.

Regional Climate Change

1. **General Statement**

   Magnitude of Change vs Scenario

2. **Specific Cases**

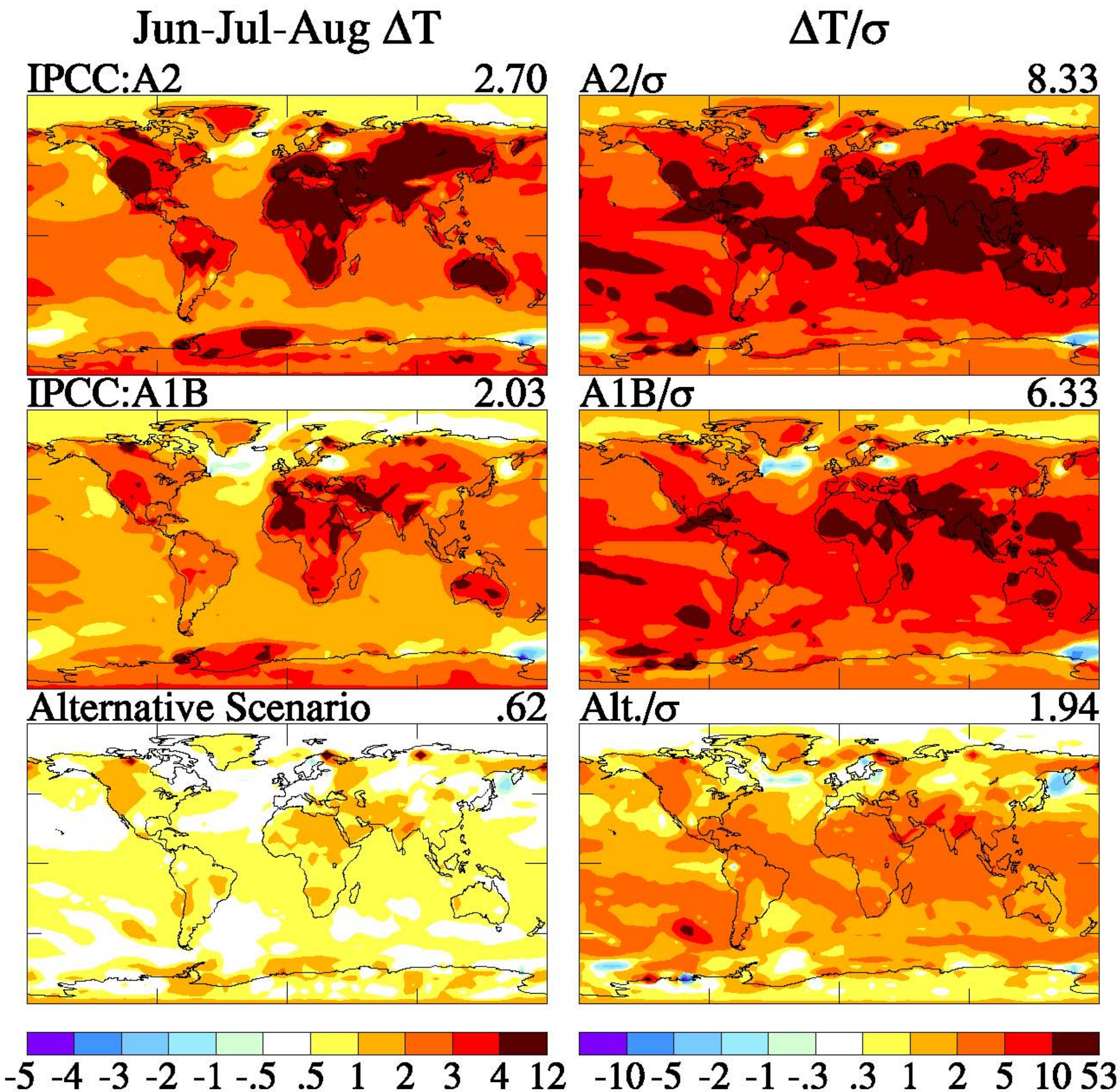
   Arctic

   Tropical Storms

   Ocean Effect on Ice Shelves

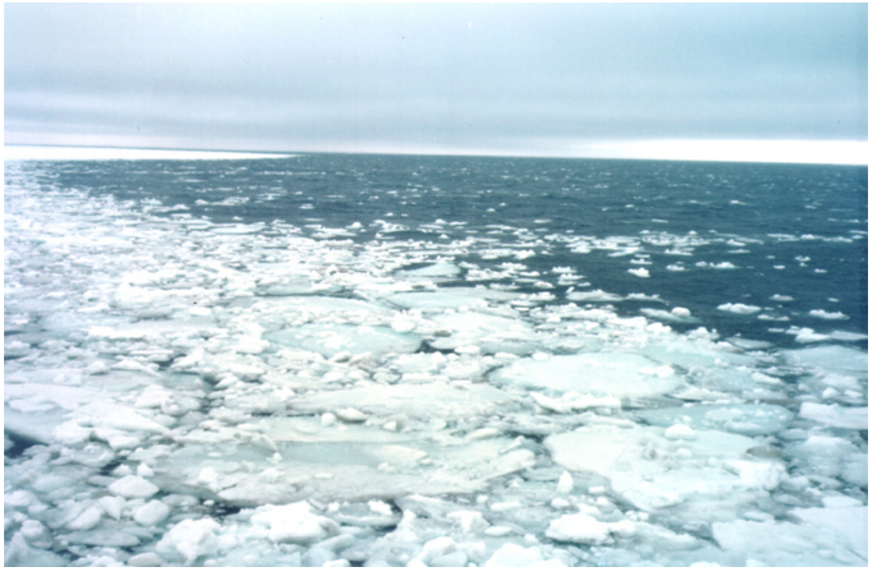
Simulated 2000-2100 Temperature Change

σ is interannual standard deviation of observed seasonal mean temperature for period 1900-2000.



Source: Hansen et al., *J. Geophys. Res.*, to be submitted.

Arctic Climate Impact Assessment (ACIA)



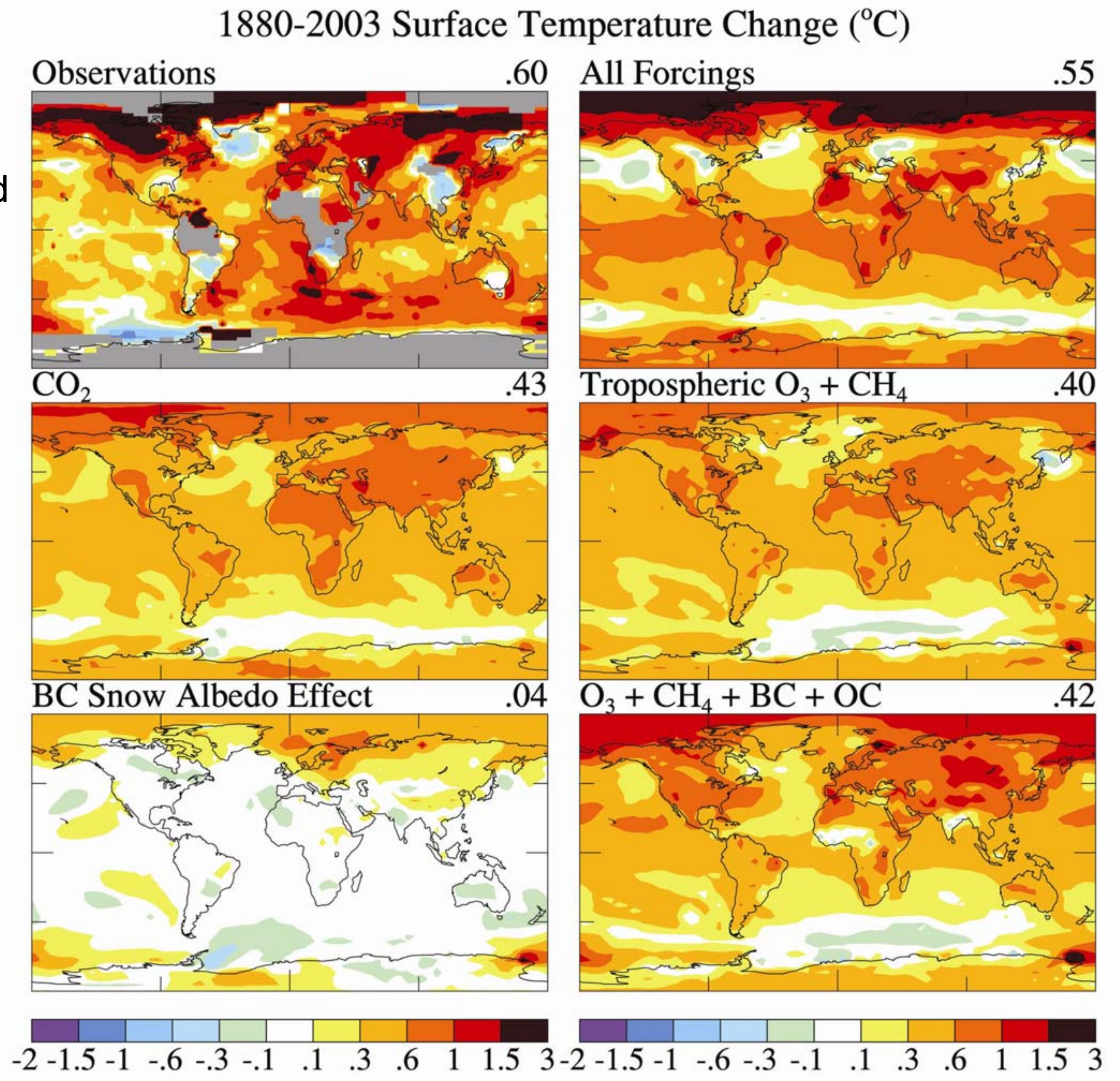
- 140-page synthesis report released in November 2004.
- Main science report imminent (chapters available electronically at www.acia.uaf.edu).
- Concerns over wide-ranging changes in the Arctic.
  - Rising temperatures
  - Rising river flows
  - Declining snow cover
  - Increasing precipitation
  - Thawing permafrost
  - Diminishing late and river ice
  - Melting glaciers
  - Melting Greenland Ice Sheet
  - Retreating summer sea ice
  - Rising sea level
  - Ocean salinity changes
- Species at risk include polar bears, seals, walruses, Arctic fox, snowy owl, and many species of mosses and lichens

Sources: Claire Parkinson and Robert Taylor

Temperature change observed and simulated for different forcing mechanisms.

Aerosol forcing (negative) is thought to be slightly excessive in in the ‘all forcing’ simulation.

Source: Hansen et al., *J. Geophys. Res.*, to be submitted.



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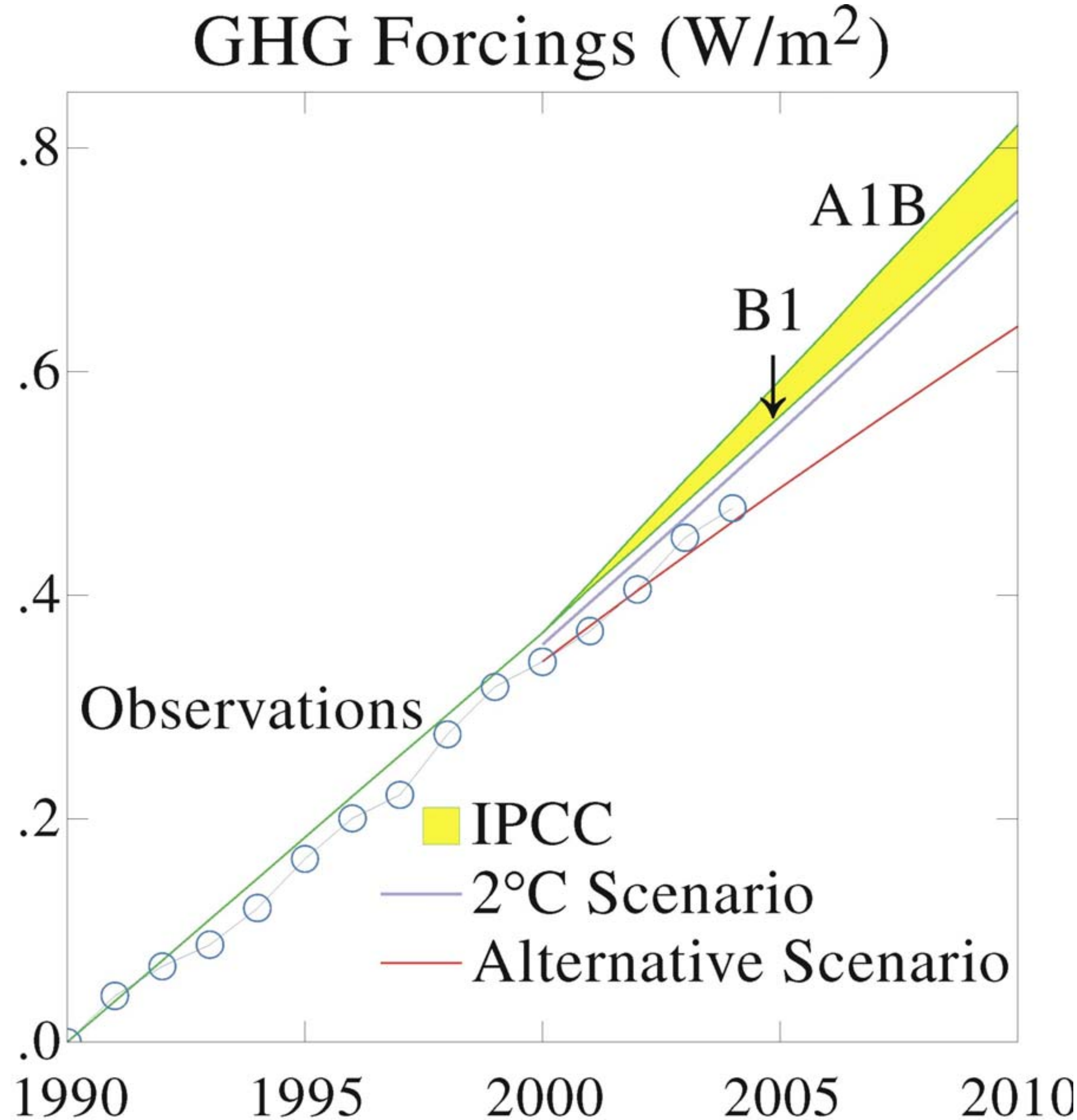
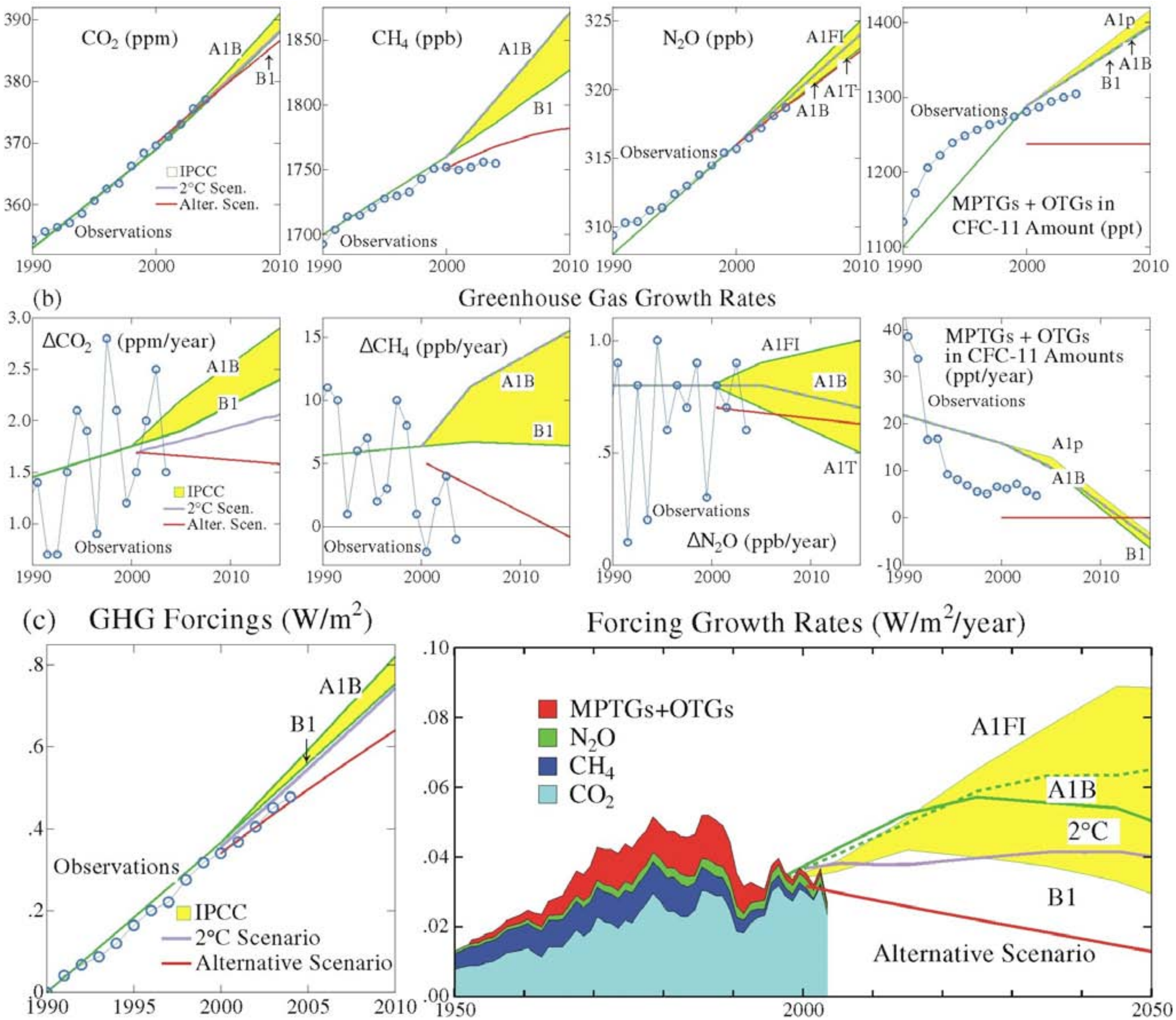
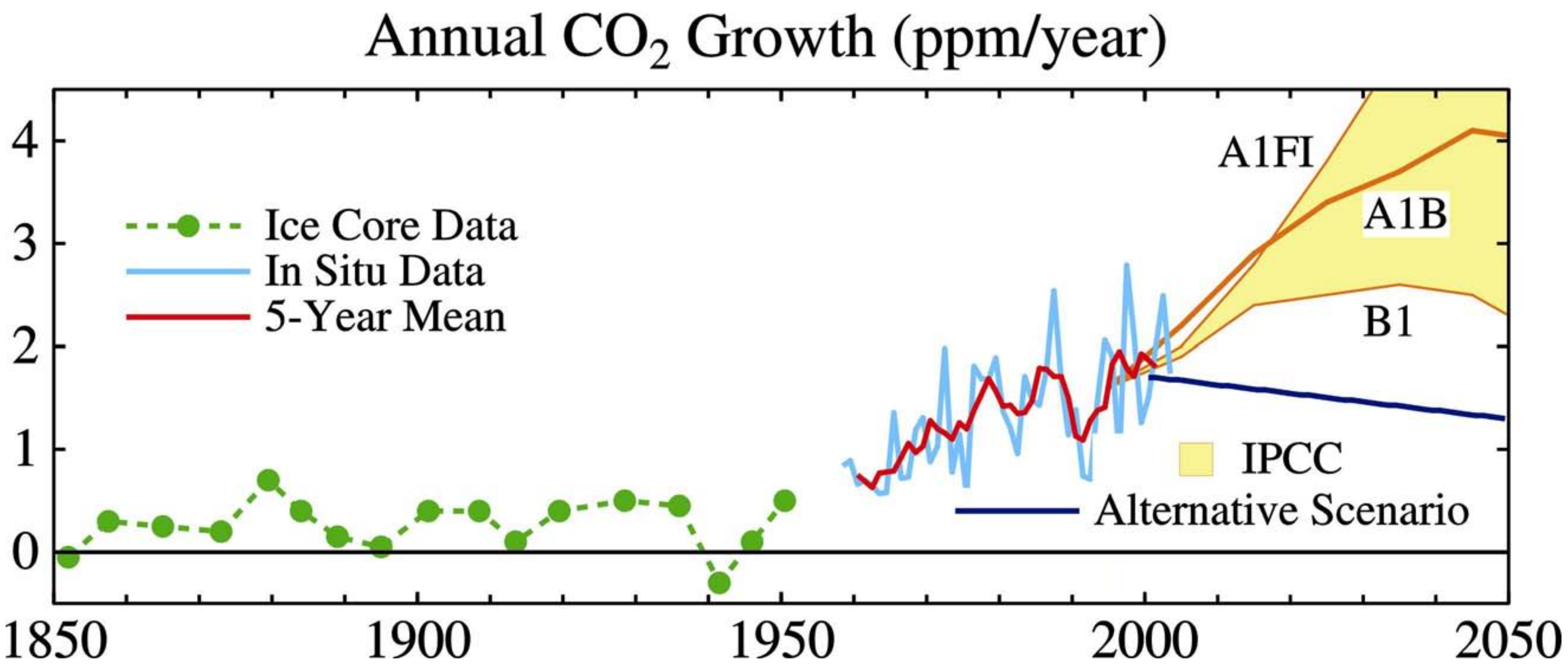


Increase of greenhouse gas climate forcings since 1990.

Greenhouse Gas Mixing Ratios



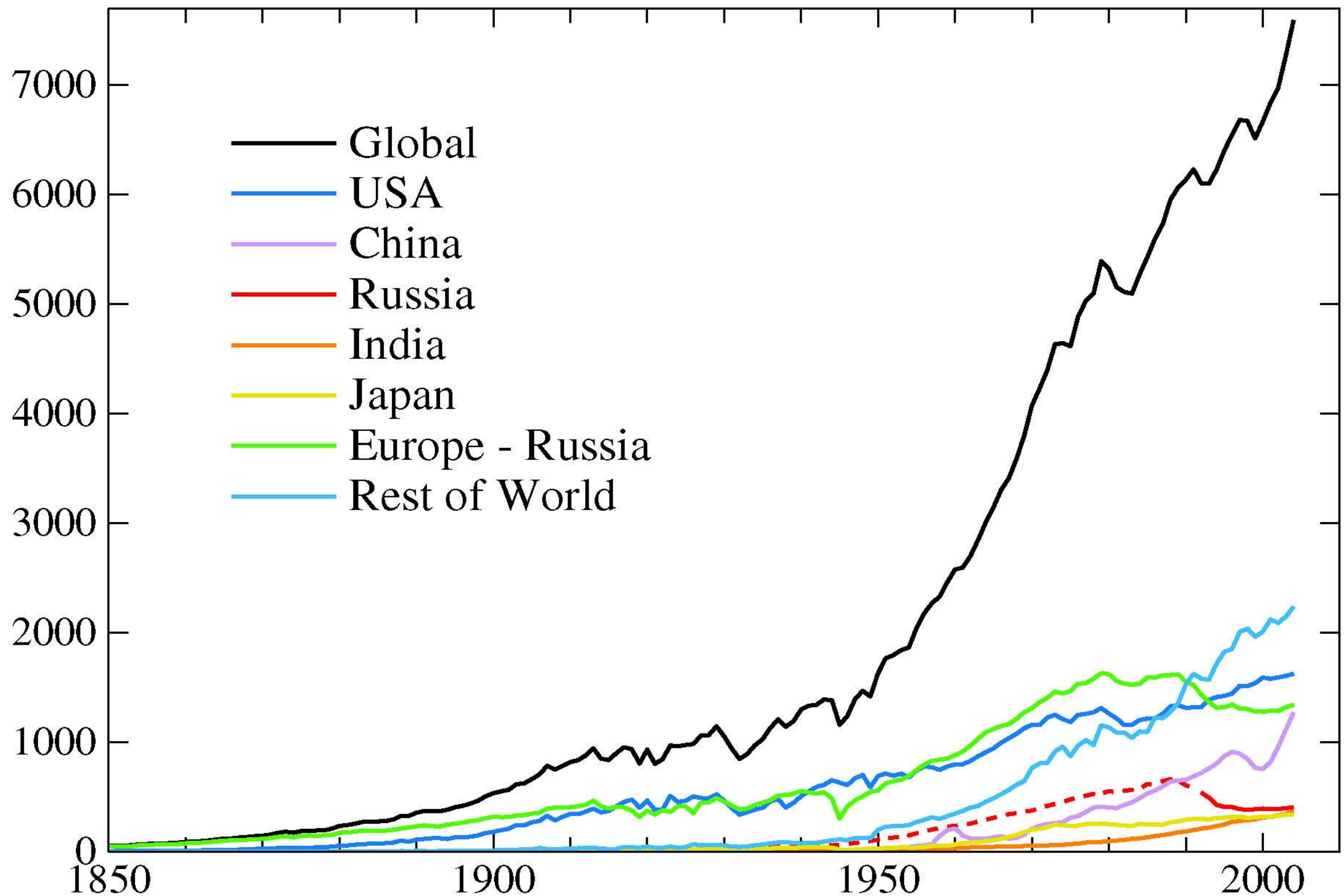
Greenhouse gas amounts (a), growth rates (b), and resulting forcings (c) for IPCC, "alternative" and "2°C" scenarios compared with observational data.



Growth rate of atmospheric CO_2 (ppm/year).

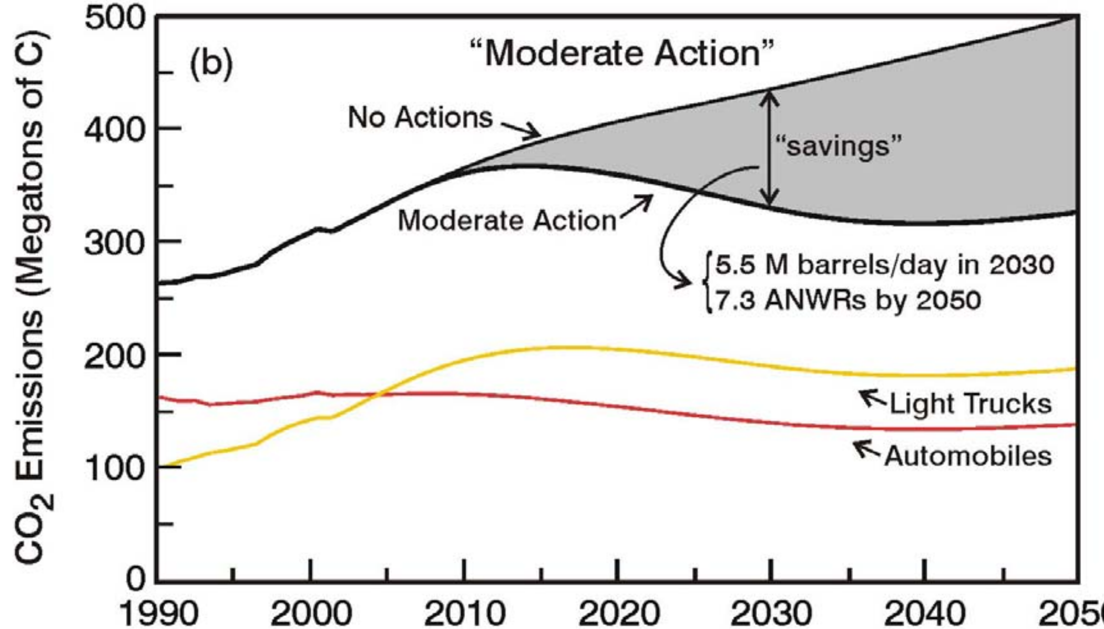
*Source: Hansen and Sato, PNAS, **101**, 16109, 2004.*

Country/Region Fossil Fuel CO_2 Annual Emissions

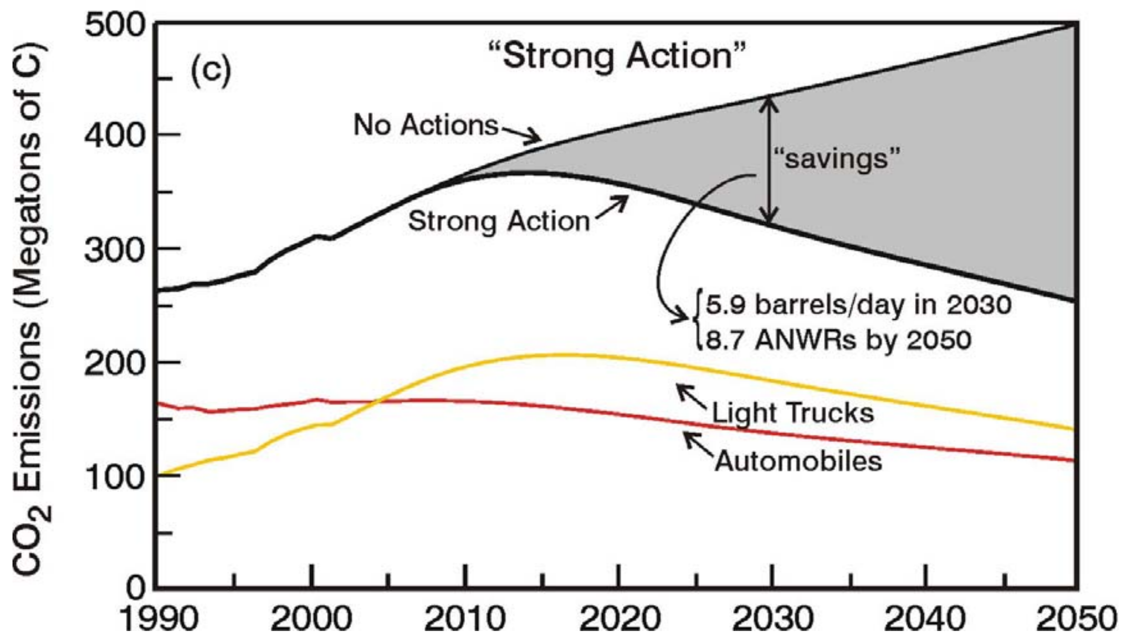


U.S. Auto & Light Truck CO_2 Emissions

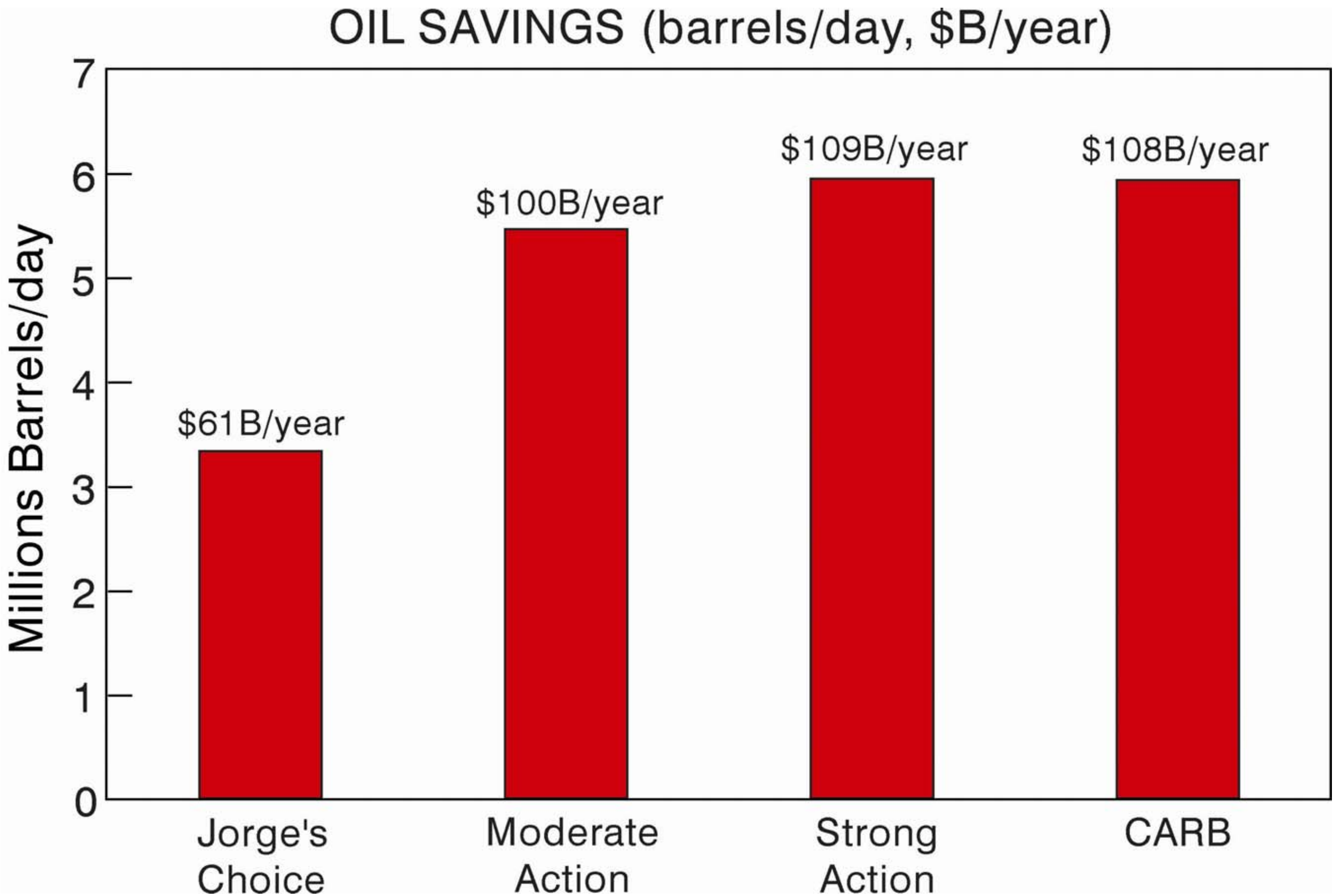
"Moderate Action" is NRC "Path 1.5" by 2015 and "Path 2.5" by 2030.



"Strong Action" adds hydrogen-powered vehicles in 2030 (30% of 2050 fleet). Hydrogen produced from non-CO_2 sources only.



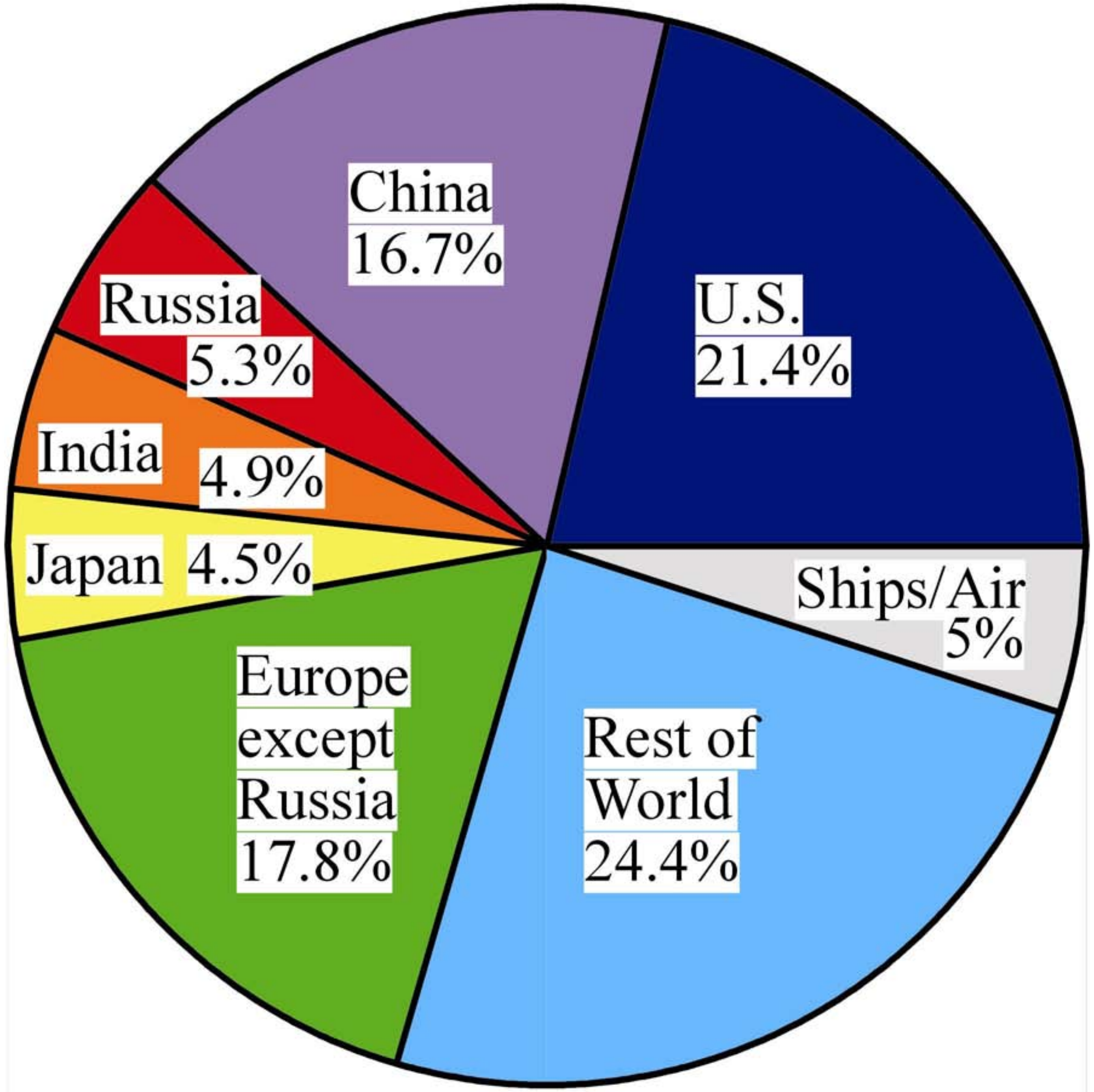
Source: On the Road to Climate Stability, Hansen, J., D. Cain and R. Schmunk., *to be submitted*.



United States annual savings (at $50/barrel, today's dollars) in 2030 for alternative automotive efficiency improvements.

Source: On the Road to Climate Stability, Hansen, J., D. Cain and R. Schmunk., to be submitted.

2004 Portions of CO_2 Emissions



Fossil Fuel CO_2 emissions by source country in 2004.

Source: Hansen et al, J. Geophys. Res., to be submitted

Workshop at East-West Center, Honolulu

April 4-6, 2005; Local Host: Intn'l. Center for Climate & Society, Univ. Hawaii

"Air Pollution as Climate Forcing: A Second Workshop"

► **Multiple Benefits by Controlling CH_4 and CO**
(benefits climate, human health, agriculture)

► **Multiple Benefits from Near-Term Efficiency Emphasis**
(climate & health benefits, avoid undesirable infrastructure)

► **Targeted Soot Reduction to Minimize Warming from Planned Reductions of Reflective Aerosols**
(improved diesel controls, biofuels, small scale coal use)

► **Targeted Improvements in Household Solid Fuel Use**
(reduces CH_4, CO, BC; benefits climate, human health, agriculture)

Conclusion: Technical Cooperation Offers Large Mutual Benefits to Developed & Developing Nations.

References:

►**Air Pollution as Climate Forcing: 2002 Workshop; 2005 Workshop** http://www.giss.nasa.gov/meetings/pollution02/ and 2005/

Summary: Is There Still Time?

Yes, But:

- **Alternative Scenario is Feasible, But It Is Not Being Pursued**
- **Action needed now; a decade of BAU eliminates Alter. Scen.**
- **We Are All in This Together**
- **Role of the Public & Scientists**